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THE APPLICATION OF ELECTRICITY AND MAGNETISM TO TRANSMISSION IN THE TELEPHONE PLANT

SECTION IV

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

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THE APPLICATION OF ELECTRICITY AND MAGNETISM TO TRANSMISSION IN THE TELEPHONE PLANT

R. A. Rymor.
N. E. Co.

SECTION IV

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

Revised 1929

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SECTION IV

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SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-A

ELECTRICAL MEASUREMENTS AT LOCAL TEST DESK

PART I

Introductory

This section deals with the fundamentals which underlie the tests made at both the local and toll test boards. To the man interested in electricity there can be no more attractive work than that which applies electrical laws to circuits in order to determine their efficiency or to locate trouble in them. The test board man in his every-day work makes use of the elements of electricity in a practical way to maintain the plant so that it will give good service. His tests and locations determine largely the speed with which trouble is cleared. Many of his tests are of a routine nature and aim to prevent trouble from affecting the operation of circuits.

The Wheatstone bridge, the voltmeter and the ammeter play a big part in this work. Their application to the testing of circuits together with that of some other types of testing apparatus used less frequently will be discussed in the following parts. Simple sketches will be shown to bring out the principles which underlie the tests made with these instruments. Some of the electrical fundamentals of the work with which the test board man comes in contact, such as superimposed direct currents on telephone circuits, will also be treated in a simple manner. The local testing work has been separated from the toll and will be treated in part A. The section on toll testing work will follow in part B and will tie in with part A to form a connected and simple story on testing work at the test boards.

Electrical Measurements at Local Test Desk

At the local test desk we are mainly concerned with exchange service as distinguished from toll service. Here we have a number of tests of like character to make throughout the day and frequently speed in testing is of great importance. However, all electrical tests should be made with enough accuracy to accomplish the purpose desired. The tests on the local boards do not attempt to obtain the refinement that the tests on the toll board do. This refinement is not usually necessary. Therefore, we find that on local test desks we confine our testing instruments as a rule to the voltmeter and ammeter.

In Section I–E we saw that the galvanometer of the D'Arsonval type contains the principles of most of our modern ammeters and voltmeters. Galvanometers of this type are so sensitive that one scale division will record a one-hundred-millionth part of an ampere. This type of instrument is too delicate to use directly in a circuit so we have to shunt most of the current in the main line away from the galvanometer. See Figure 1. The fraction of the main current that passes through the galvanometer and the part that passes through the shunt can be easily determined, for we know the resistance of the moving coil and that of the shunt for a given type of meter. We can figure out the division of the current in these two paths according to the methods outlined in Section I–C for parallel circuits. Since we can control the relation that the current through the moving coil bears to the current in the main line it is evident that the scale of the galvan-

ometer can be calibrated to read the units of current which we wish to measure in the main line.

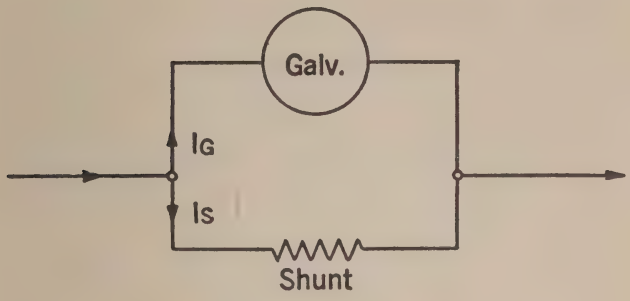


Fig. 1

The Weston ammeter and voltmeter of the common type (the principle of which was described in one of the preceding sections) are, as a matter of fact; millivoltmeters. In these instruments a small voltage of about 45 millivolts or less will give full scale deflection when impressed across the moving coil of the meter. In order to make this instrument an ammeter capable of carrying and recording a fairly large current it is necessary to place a shunt across the moving coil. In many of the instruments for recording currents of small magnitude the shunt is placed within the case. Where the current to be measured exceeds 25 amperes, as a rule the shunt is placed outside the case in order that the heat from the shunt may be dissipated.

This same instrument, the millivoltmeter, can be used to measure voltage by placing a high resistance (or as it is called, a multiplier) in series with

the moving coil. This multiplier is usually placed inside the case of the instrument.

The volt-milammeter of the No. 12 Local Test Desk requires no shunts outside the case of the instrument. Let us briefly consider this meter and from its construction and operation it will be possible to determine the performance of the various other meters of similar type that we meet with in our testing work.

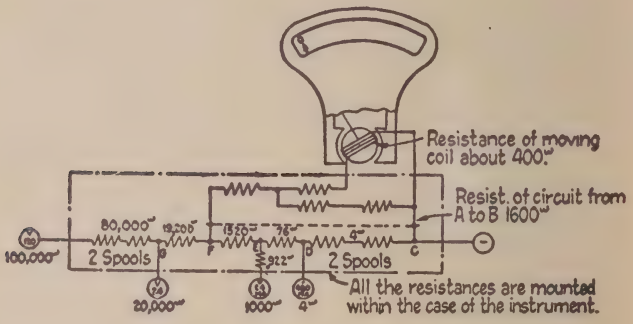


Fig. 2

Figure 2 shows the circuit of this meter. The five binding posts are shown by the circles. Let us first consider this meter as a milliammeter. To use it as such it will be necessary to connect the circuit under test to binding posts "—" and "480 M.A." The 4-ohm coil will be in the main circuit forming the main line shunt. The circuit through the moving coil can be traced from one side of the shunt **D** through the 76- and 1520-ohm resistances to **F** then through the circuit from **A** to **B** and back to the other side of the shunt **C**. The moving coil is in the portion of the circuit from **A** to **B**.

The scale is so calibrated that the meter records the number of milliamperes flowing in the main circuit. We can see that only a small portion of the main current flows through the moving coil.

Now let us consider this meter as a 20,000-ohm voltmeter. In order to use it as such we must connect our circuit to binding posts "—" and "V–24, 20,000 ohms." The resistance which the meter then offers to the main circuit is 20,000 ohms. The portion of the circuit from **C** to **F** which is equal to (4 + 76 + 1520 =) 1600 ohms is in parallel with the circuit from **A** to **B** which is also 1600 ohms. This combination gives us 800 ohms which is in series with the 19,200 ohms from **F** to **G**. This series parallel circuit from **C** to **G** gives us, therefore, 20,000 ohms. Again we can see that the current through the moving coil is only a small fraction of that which flows in the main circuit. Now, however, the scale is calibrated in volts instead of milliamperes and indicates the voltage which is impressed across the binding posts we are considering. We saw in one of the preceding sections that the current through the moving coil of the meter is proportional to the voltage across its terminals, therefore, the amount the coil turns must be proportional to the voltage.

In the test desks found in telephone practice it is possible by the proper operation of keys in the testing circuit to connect the line under test to the various posts of the meter; thereby selecting the type or scale of meter desired. In the case of the No. 12 desk, the one meter has five different applications, any one of which is selected by the proper operation of keys in the testing circuit.

In order to concretely tie down the elements of testing to telephone work let us consider the tests which can be made on the No. 12 local test desk. These tests, however, will be considered only in a general way in order to bring out the principles involved so that they can be applied to any other type of desk found in the plant.

Continuity and Ground Tests

In order to have a current of electricity flow in a circuit when a voltage is placed in series with it the circuit must be closed or continuous. If then we insert a suitable meter in the circuit we can detect and measure the amount of current flowing. The meter can be of the type usually called an "ammeter" or it can be what is commercially termed a "voltmeter." It should be understood that we are now considering direct current effects.

Let us take a case where we use the milliammeter in the circuit. Figure 3 shows a schematic of a cir-

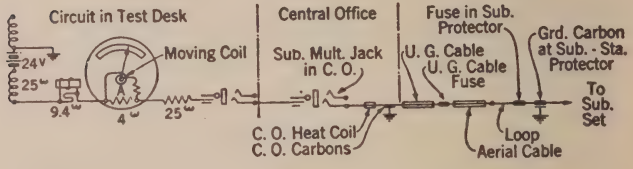


Fig. 3

cuit obtained when we operate the proper keys in the test circuit of the No. 12 desk. The current flows from the positive side of the battery through the earth to the "ground" at the subscriber's protector over the subscriber's line and the circuit in

the central office to the negative side of the battery. The current which flows in the resistance **A** causes a voltage "drop" which we can look upon as a battery which has the same voltage as the number of volts drop in **A**. This voltage is impressed across the terminals of the moving coil (which we will note has a resistance in series with it), and causes a current to flow through it which in turn causes the needle of the meter to be deflected. The reason for this deflection was discussed in previous sections. The resistance **A** is small being less than 10 ohms.

Let us now assume that we have what is generally termed a "voltmeter" in the circuit. Figure 4 shows a condition obtained when we operate the proper keys in the testing circuit. Here again we

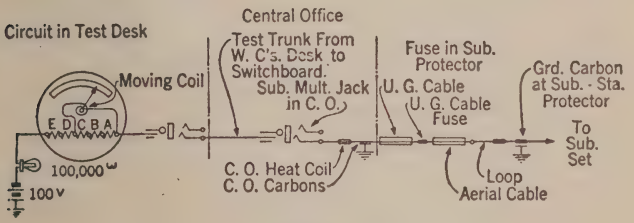


Fig. 4

get a similar action of the current in the meter. We will note that the current in the main circuit divides when it reaches the meter, part of it flowing through resistances **A**, **B** and **C** and part through the moving coil. We can also look upon the electrical action in the meter in a manner similar to that described in the preceding paragraph in that the current causes a drop through resistances **A**, **B** and **C** which represents the voltage impressed

across the moving coil. It should be noted that in the particular setup shown in this figure there is no resistance in series with the moving coil as was the case in Figure 3. However, there is a large resistance placed in series with the external circuit which causes a small current to flow. As pointed out previously this type of meter requires only a small voltage across the moving coil in order to have the needle give full scale deflection.

Let us consider another setup obtained by the proper operation of the keys in the test circuit. Figure 5 shows a circuit which measures the current

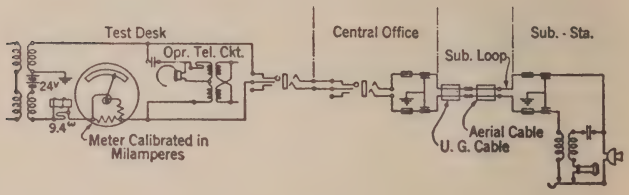


Fig. 5

that flows through the transmitter of a subscriber's set. In this circuit we use the portion of the meter known as the "milliammeter." Figure 6 shows a circuit which measures the resistance of an inter-

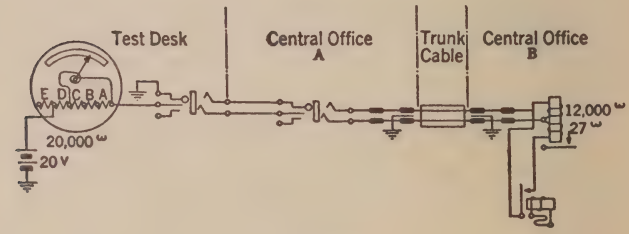


Fig. 6

office trunk. Here we use the portion of the meter known as the "voltmeter." In these circuits we must have a continuous or closed path in order to obtain a flow of current to give us the opportunity of obtaining an electrical measurement.

Let us return to the example shown in Figure 4. Here we have a testing voltage of 100 volts. This is obtained from dry cells. This battery is poled opposite to the central office battery, that is the negative side of the test battery is grounded if the positive side of the central office battery is grounded. A 20-volt tap is taken from the same battery to supply voltage to the 24-volt scale of the meter. As shown in Figure 3 the central office battery of 24 volts (22 to 28 volts) is used in the milliammeter circuit.

It should also be noted that in the No. 12 desk the 100-volt test battery is used with a scale reading of 120 volts and that the 20-volt test battery is used with a 24-volt scale deflection. The reason for having this scale deflection in excess of the test voltage is to provide a means of readily determining from a voltage reading whether any of the lines

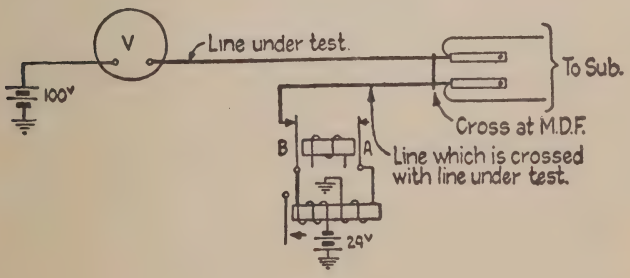


Fig. 7

under test are crossed with other lines in the exchange. Figure 7 shows a line under test which is crossed with another line in the central office. Note that the voltage impressed across the terminals of the voltmeter is approximately 124 volts, due to the test battery of 100 volts, which is poled opposite to the central office battery being in series with the 24 volts in this latter battery. Since the meter reads 120 volts it will be possible to approximately read the total voltage impressed on the circuit. This shows us that the reading obtained under such conditions would be in excess of 100 volts by an amount equal to the voltage of the central office battery.

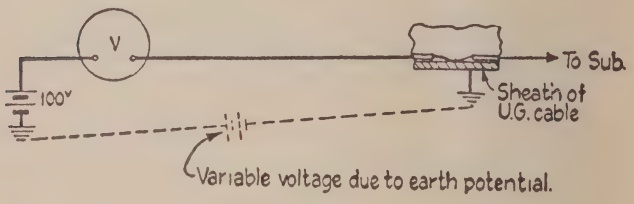


Fig. 8

In Figure 8 is shown a sketch of a circuit obtained when the proper testing combination is set up. Between the point where the testing battery is grounded and the point where the line under test is grounded, we have in the earth itself a variable voltage known as "earth potential." This voltage in addition to not remaining constant sometimes reverses its polarity. We can readily see that this voltage either adds to or subtracts from the testing voltage and affects the reading obtained in the tests. Figure 9 shows a circuit obtained when we make a test for the insulation resistance of one side of a line. If the cable pair under test is clear and the insula-

tion of the line fair (say 20,000 ohms) the high testing voltage of 100 volts would prevent an ap-

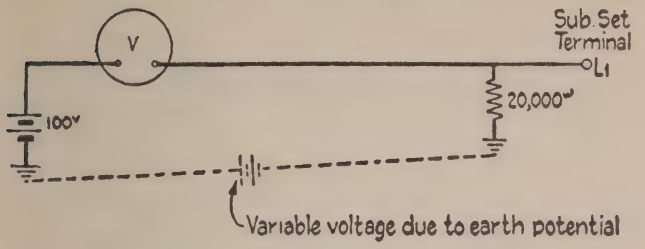


Fig. 9

preciable error in the test when earth potential is present.

Resistance Measurements

Resistance measurements can be made with a voltmeter with a reasonable degree of accuracy. We should be careful, however, to see that the resistance of the voltmeter is approximately equal to the external resistance of the circuit under test in order to obtain the most accurate results. For this reason we have the various combinations of the volt-milliammeter in the No. 12 desk. The four resistances obtained with this meter are 100,000 ohms, 20,000 ohms, 1,000 ohms and less than 10 ohms. The first three resistances are used with the scale that is calibrated in volts and the fourth is used with the scale that reads in milliamperes.

The milliammeter is best adapted to measuring resistances under 500 ohms. It can be used with good results for detecting a receiver off the hook at a substation (see Figure 5), lines plugged up at

P.B.X.'s, wet desk stand cords, etc. The 1,000-ohm winding is best suited to detect short-circuited condensers in the subscriber's set, sticky relays in four-

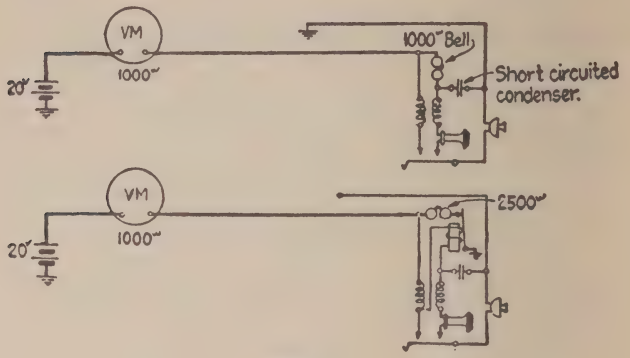


Fig. 10

party subsets, etc. (see Figure 10). The 20,000-ohm winding can be used to check the resistance of 108-type relays at the incoming end of interoffice trunks (see Figure 6), etc., and the 100,000-ohm winding for checking the insulation resistance of subscribers' and trunk lines (see Figure 9).

In order to calculate the resistance of a line under test when a voltmeter is used, we must consider the resistance of the voltmeter and the voltage of the test battery.

Let us call the external resistance to be determined **X**.

The resistance of the voltmeter **R**.

The voltage of the test battery **E**.

and

The reading of the voltmeter E_1.

$$X \text{ then equals } \frac{E - E_1}{E_1} R.$$

This can be stated in another way, that is, to obtain the external resistance of the circuit under test.

First, subtract the reading of the voltmeter from the voltage of the test battery.

Second, divide the number just obtained by the reading of the voltmeter.

Third, multiply this last number by the resistance in ohms of the voltmeter.

This gives us the resistance of the circuit we are testing.

This same formula applies when measuring a resistance with the milliammeter. However, it should be understood that the resistance of the meter in this case includes any resistance placed in the test circuit in series with the external resistance which is being measured. Figure 11 shows a

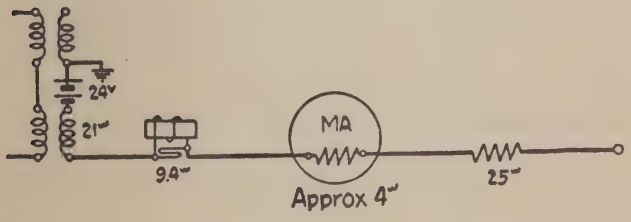


Fig. 11

sketch of the condition referred to. We will note in this circuit that the total resistance to be used in

the calculation for the resistance of the meter is approximately 60 ohms. When using the milliammeter we can also determine the resistance of the circuit which is being measured by the following formula:

$$X = \frac{E}{I} - R_1$$

Where X is the resistance being measured,

E the voltage of the central office battery,

I the current flowing as indicated by the milliammeter reading, and

R_1 the resistance of the ring side of the test circuit which equals approximately 60 ohms in the condition shown in Figure 11.

This relation can be stated in the following way.

The external resistance equals:

The voltage of the central office battery divided by the amperes indicated by the milliammeter minus the resistance in ohms of the test circuit.

(Note that the meter reads in milliamperes which are one-thousandth parts of an ampere.)

Test for Insulation Resistance and Leakage

We are not called upon as a rule to maintain local telephone lines to the same high grade of insulation as toll lines. Machine switching systems, however, demand a higher grade of insulation than manual systems. This insulation resistance which determines the amount of leakage of current in our circuits is considered in two ways. First, the insulation resistance of each wire of a pair to ground, and second, the insulation resistance between the wires

of a pair. Figure 12 shows the method of obtaining a measurement of the insulation resistance to ground. We will note that the leaks to ground are distributed along the entire length of the circuit and form a series parallel path. Let us consider Figure 12. Here the insulation resistance of each ½ mile

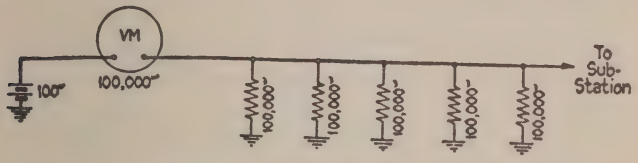


Fig. 12

of line is grouped at the middle of the section and each is equal to 100,000 ohms. We have for the total circuit a resultant resistance of approximately 20,000 ohms to ground. The series resistance of the line is neglected. This is low and will not appreciably affect the result.

The voltmeter deflection can be used in the following formula to give the insulation resistance of the entire length of this side of the pair.

$$X = \left(\frac{E}{D} - 1\right) \times 100{,}000$$

Where X = resistance being measured.
E = testing battery voltage.
D = deflection of voltmeter.
100,000 = resistance of voltmeter.

Let us say that in the test made in Figure 12, we obtained a reading of about 83 volts and that the test battery tested 100 volts. (We must, of course, use the 100,000-ohm winding of the meter.) Let

us determine the insulation resistance of the line shown in Figure 12. By applying the above formula, we have—

$$\frac{E}{D} = 100 \div 83 = 1.2 \text{ (approximately).}$$

$$\frac{E}{D} - 1 = 1.2 - 1 = .2$$

$$\left(\frac{E}{D} - 1\right) \times 100{,}000 = 20{,}000 \text{ ohms the insulation resistance of the line.}$$

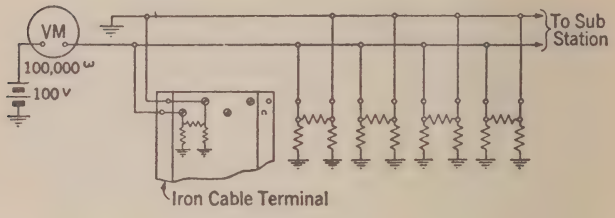


Fig. 13

Figure 13 shows the circuit obtained when we make a test on a certain subscriber's line. The

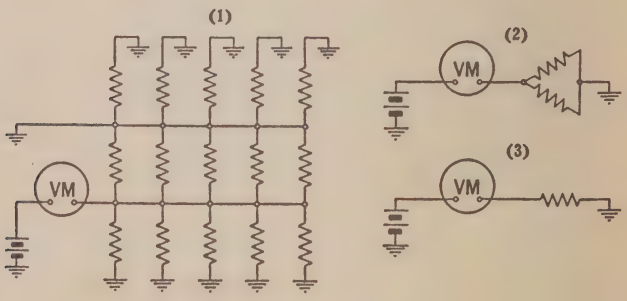


Fig. 14

aerial cable pair which is connected to this line appears in five aerial cable terminals. Let us assume that moisture has affected the porcelain face of the terminals and has produced a low resistance leak across the pair and to ground. Note how these resistances combine to form one low resistance path across the pair and to ground. We can determine this resultant resistance by a voltmeter test as indicated in the sketch. The small sketches in Figure 14 show how the conditions shown in Figure 13 can be simplified. In sketch 1, the resistances which represent the circuit of Figure 13 are grouped so that we can more clearly see the interrelation of them. Sketch 2 shows how the circuit can be simplified by properly associating the resistances in sketch 1. Sketch 3 shows how the problem finally simplifies itself. We can now see how this case represents that of Figure 13 and how the same formula given above can be used to calculate this resistance.

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-A

ELECTRICAL MEASUREMENTS AT LOCAL TEST DESK

PART II

This is a continuation of the discussion on testing work begun in Part 1. Reference is made to figures and other information contained in that part so we must therefore consider the two parts as forming one continuous story describing the testing work at the local test desk.

Test for Crosses

Crosses may be divided into two classes, those between the wires of a pair, known as short-circuits and those between either wire of a pair and another circuit. This other circuit may or may not have battery or ground connected to it. Figure 7 shows a cross between a wire under test and another wire which is connected to a 24-volt battery. If the wire which is connected to the " B " contact of the cutoff relay were connected to the " A " contact we would have a case where the wire under test would be crossed with a grounded circuit. In this case the 100 volts of the test battery would be the only voltage impressed on the circuit, instead of the 124 volts as in the other case. Crosses between the wires of a pair can be measured as shown in Figure 13. The resistance in this case will be low depending on the resistance of the cross and the series resistance of the line.

Tests for Foreign or Earth Potentials

In Figures 8 and 9 we have a condition where a source of battery other than the test battery was included in the testing circuit. It is often desirable to know the amount of this foreign voltage. By removing the test battery and substituting ground in its place, we have a very efficient circuit to

measure this voltage. By using the 100,000-ohm winding of the meter, earth potentials can be measured with considerable accuracy. In case the cir-

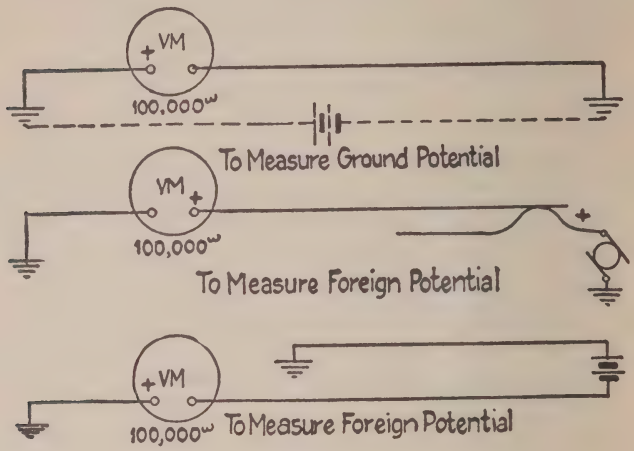


Fig. 15

cuit under test is crossed with foreign potential, it is possible by operating the proper keys to replace the testing battery with a direct ground and measure the voltage of this foreign battery. See Figure 15. The No. 12 desk has its test circuit so arranged that by the proper operation of keys the voltmeter will show the voltage of the test battery.

Current Flow Measurements

Figure 3 shows that the meter can be used as a milliammeter to indicate the current flowing in the circuit under test. Figure 11 shows a fixed resistance and the milliammeter in the testing circuit of the No. 12 desk. We can see that this setup differs

somewhat from the usual conception of an ammeter in that there is about 60 ohms resistance included in the circuit which is being tested instead of only a meter with negligible resistance. Figure 5 shows a circuit obtained when the proper keys are operated in order to measure the current flowing through the transmitter of the common battery subscriber's set. It will be noted that the 60-ohm condition mentioned above is now changed. The new setup gives a condition which closely resembles the condition obtained when a subscriber is connected to an "A" operator's cord circuit. In other words, it closely checks the battery which is supplied to the subscriber's transmitter when the telephone is being used in a regular connection.

Capacity Tests

We now come to a consideration of the voltmeter when it is used to determine the capacity of the line under test. One of the requirements of a subscriber's line, particularly in a machine switching system is that its capacity does not exceed a definite amount. The condenser in the subscriber set usually determines this capacity.

In the foregoing sections we have seen that conductors and particularly condenser plates will accumulate charges of electricity of a fixed polarity (either positive or negative). These charges of electricity will discharge into another conductor or the earth or into a battery of different potential and cause a momentary current to flow. It should be noted that if the condenser plates which have a definite charge are connected to the poles of a battery of like potential no current will flow in the

circuit thus established. In order to obtain a momentary flow of current in the circuit which contains a battery and a condenser, which let us say is already charged, either the polarity of the charge on the condenser plates must be opposite to that of the poles of the battery to which they are connected, or the potential of the battery and the potential of the charge on the condenser plates must be of a different value in case the charged condenser plates are connected to the terminals of the battery of like polarity.

Now if we place a meter in the circuit when this momentary current flows we will get a reading which can be used for practical measuring purposes. (See Figure 16.) Sketch 1 shows a condenser con-

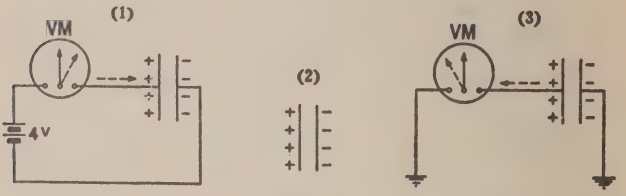


Fig. 16

nected to a battery. The condenser becomes charged as shown and causes the voltmeter needle to "kick" across the scale in the direction shown. The condenser retains this charge as shown in sketch No. 2 if it is carefully insulated from any other objects. Sketch 3 shows the condenser which has one side connected directly to ground and the other side through the voltmeter to ground. We will note that again a momentary current flows through the voltmeter and causes the needle to

"kick" across the scale in a direction opposite, however, to the direction in which it moved before. It can be shown that if the whole discharge is passed through the meter before the needle has been moved, the limit of the first swing of the needle is a measure of the quantity of electricity that has passed. Therefore, by having a fixed voltage in the testing circuit we can determine the capacity of a condenser by noting the discharge through the voltmeter after we have determined the extent of the "throw" of the needle from tests on known capacities.

This explains why we must carefully consider the method of testing when we perform the tests which are usually termed "ballistic" tests. When performing these tests care must be taken to see that the needle comes to rest before starting each new operation. To do otherwise is to introduce an error in the reading of the instrument from a "ballistic" standpoint. Generally speaking, no tests should be made until the needle of the instrument comes to rest from a deflection caused by a previous test or some circuit change in the testing connection.

Let us go through the operation of testing a line and see how we obtain the measure of the capacity of the circuit. Figure 17 shows a schematic of both a direct and a two-party line up on test. Before the lines were connected to the test circuit the condensers in the suscriber sets were charged, let us say, from the Central Office battery supplied through the line circuit. These charges are indicated in the figure. When the test circuit is connected to the line under test a momentary current flows in the circuit shown in the figure. This is due to the

polarity of the condenser being different from that of the testing battery. This causes a deflection of the needle. By operating the key which connects

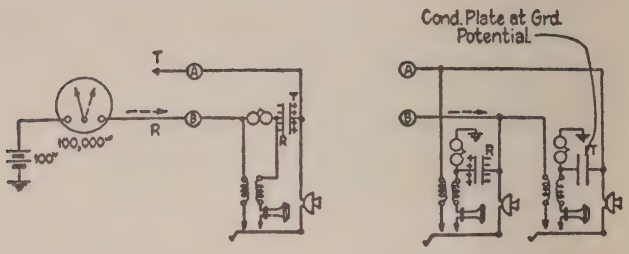


Fig. 17

ground to the tip side we obtain the circuit shown in Figure 18. The condenser now takes a definite

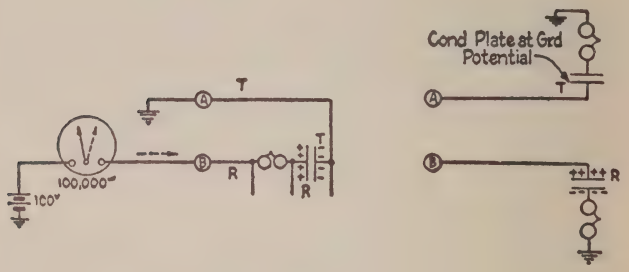


Fig. 18

charge from the test battery which again causes some sort of deflection of the needle. These operations are preparatory to the inportant parts of the test which follow and measure the capacity of the circuit.

After the needle has come to rest, let us operate the key which reverses the test circuit. We then obtain the condition shown in Figure 19. At the

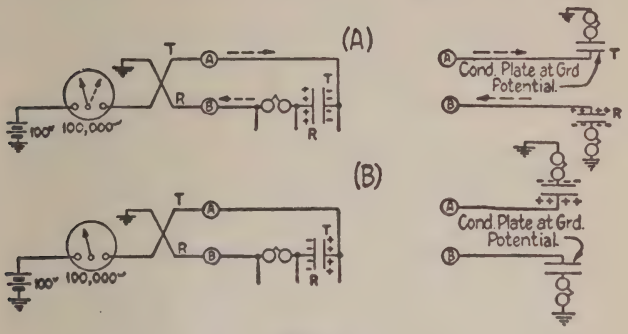


Fig. 19

instant the key is thrown (see Sketch A), a charge from the test battery rushes out to the **T** condenser plate causing the needle of the meter to "kick" across the scale. The plus charge of the **R** plate rushes back to the negative side of the battery. We have thus obtained a deflection of the needle which measures the capacity of the condenser across the line. After this rush the current through the circuit stops flowing and the condenser takes the charge shown in Sketch B.

The sketch also shows the charges impressed upon the condenser in the subset of a two-party station. In the particular setup obtained in this test we are able to determine the capacity connected from the tip side of the line to ground which gives us the capacity of the condenser in the subset which is connected to this side of the line.

After the needle has come to rest from the pre-

ceding test, let us restore the reversing key. We then obtain the circuit shown in Figure 20. At the instant the key is thrown (see Sketch A) a charge from the test battery rushes out to the R condenser plate which causes the needle of the meter to

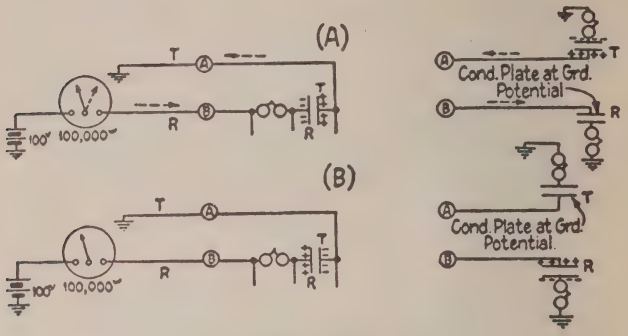


Fig. 20

" kick " across the scale. The plus charge from the T plate rushes back through the earth to the test battery. As in Figure 19, we have obtained a deflection of the needle which measures the capacity of the condenser connected across the line or the capacity of the condenser connected from the ring side of the line to ground depending upon the type of substation bell circuit. After this rush the current stops flowing and the condensers take the charges shown in Sketch B.

In the foregoing tests we have seen how a condenser which has taken a charge of electricity will give up this charge when the opportunity offers itself. When this charge is given off in a circuit a momentary current flows which causes a similar effect on our apparatus to that caused by a momen-

tary current from a battery. The size of the condenser (that is the number of microfarads it is rated at) determines the amount of the charge the condenser can hold and, therefore, the amount of energy it will discharge into a circuit. That is why different sizes of condensers give a different "throw" to the voltmeter needle.

We have already seen that by combining condensers in series we cut down the resultant capacity but by connecting them in multiple we increase the capacity of the group. In our station connections we secure a different capacity effect for different combinations of subscriber sets, for instance, four subscriber sets of the four-party type each containing a one microfarad condenser when connected across a line would give practically 4 mf. If, however, these sets each contain a 2-mf. condenser the resultant capacity would be 8 mf., or if each of the 1-mf. sets had an extension similar to the main station bridged across the line in such a way that it placed a 1-mf. condenser across the line, we would again have 8 mf. Our instructions give us the limitation on the amount of capacity we can place across our subscriber lines. In order to check this point, however, we must resort to some means of testing. The "ballistic" tests of the voltmeter as described above afford this opportunity.

In this connection it might be well to consider some of the effects we secure in our circuits due to the discharge of a condenser. Take, for example, the case of a 550–C P.B.X. trunk in a step-by-step type of Machine Switching Office. On calls incoming to the P.B.X. the condenser in the trunk circuit takes a charge of a certain polarity from the con-

nector circuit. When the operator at the P.B.X. takes down her cord from the trunk jack the connector releases and battery is then supplied to the trunk from the line switch. Under certain conditions when the cross connection on the I.D.F. is not properly connected, the polarity of the battery supplied by the line switch is opposite to that of the charge on the condenser left there from the connector circuit and a pulse of current rushes through the line winding of the trunk relay at the P.B.X. which in turn locks up and brings in the trunk lamp thereby producing a false signal. Such a case of trouble is particularly annoying. When the cross connection at the I.D.F. is properly connected the condenser at the P.B.X. takes a charge from the local connector circuit which is not only of the same voltage as that impressed on the line from the line switch circuit but it is also of the proper polarity so that the condenser plate which has a positive charge is connected to the side of the line which is connected to the positive side of the central office battery and the condenser plate which has a negative charge is connected to the side of the line which is connected to the negative side of the Central Office battery. This condition consequently allows no current to flow and the relay in the trunk circuit of the P.B.X. does not operate. Here and there we find a condition in the plant where we must guard against a flow of current in a circuit (when it should not flow) due to a condenser taking on a charge of electricity of the wrong polarity or to the condenser plates being charged to a potential of a different value than that of the battery to which it is connected even though the polarity of the battery and the condenser is the same.

Breakdown Tests

It is important to have our lines built and maintained at such an insulation resistance that they will not break down under the various operating voltages which are applied. Not only must we consider the 24- and 48-volt potentials but also the voltage of our ringing machines and coin collection batteries. For this reason we apply a testing voltage of 200 volts through a suitable resistance and the milliammeter which indicates when the circuit breaks down. In the design of the circuit on the No. 12 desk, care has been taken to prevent bell tapping during the breakdown testing period by allowing the condenser at the substation to charge slowly when the 200 volts is impressed on the line and again to discharge slowly to ground when the testing voltage is removed. This is accomplished by placing a high resistance in the circuit during these two periods.

Transmission Tests

We have already seen that in order to secure a proper telephone connection it is necessary to have, in addition to other things, satisfactory station conditions. The loop and the apparatus must be built and installed and then maintained in such a way that good service can be given. In the No. 12 desk we have testing apparatus which will give us among other tests, some that will tell us whether the transmission factors of our station circuits are satisfactory. These tests embody the following features:

(a) A variable resistance or rheostat is provided which can be used to equalize the battery

supply to the different stations (that is, the current through the transmitter of the station under test), in case it is desired to obtain as far as possible by this means a uniform test condition.

(b) The use of a circuit called an artificial line (which is nothing more than a group of resistances and a condenser which acts like a given length of cable) connected in the talking circuit between the station under test and the test board man's telephone set. The reason for this setup is to increase the transmission equivalent of the circuit to about 30 db which represents the limit of good transmission to be obtained on a toll or long distance connection. It should be noted that generally the experience is that small differences in the volume of transmission can be more readily detected where the total transmission equivalent is in the neighborhood of 20 or 30 db.

(c) A talking test between the test board man and the installer or troubleman at the station. This means that, in order to obtain a proper comparison between the transmission obtained on the loop under test and that of another loop, either on the same or different days, it is essential that the testers use care and talk in the same manner and with their lips in the same relative position with respect to the transmitter in each test. This test should make it easily possible to discover defects which would cause any serious transmission losses.

Other Tests

It is often desirable to test the operation of a relay in such a way that the current flowing

through the winding of the relay can be regulated and measured. The test made with the current flow test set (which finds common use in the testing of relays both in P.B.X. and central office circuits) are somewhat similar in principle to the test referred to. Figure 21 shows a schematic of a

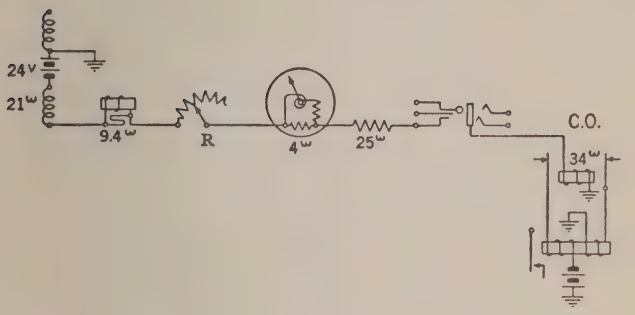


Fig. 21

circuit obtained when a cutoff relay is being tested from a No. 12 desk. By means of the rheostat R the current through the **CO** relay can be controlled as indicated in the sketch. The voltmeter and its associated test battery can be used in place of the milliammeter when the proper keys are operated in the desk. This circuit affords a means of measuring the sleeve resistance of circuits, as for example, the 34-ohms resistance in the sleeve of an outgoing trunk.

In a somewhat similar way " coin collection current " of positive or negative polarity can be connected to a line with the milliammeter in the circuit. With this setup we are able to test the operation of the coin box relays.

It is often desirable to know whether the relays in four-party sets operate properly. When the proper keys are operated in the No. 12 desk, a circuit is obtained as shown in the schematic in Figure 22. Ringing current is sent out on the line by induction through the repeating coil. The voltmeter (1,000-ohm winding) is connected to the cir-

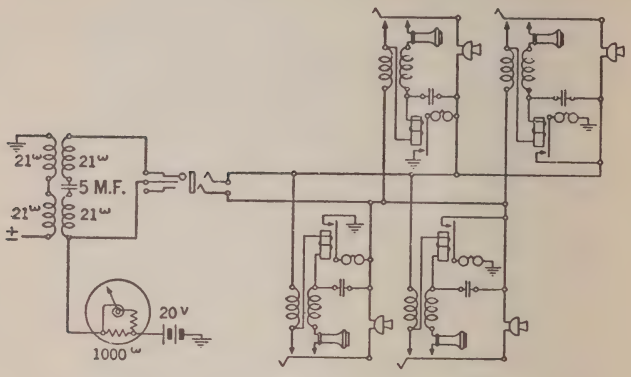


Fig. 22

cuit as shown. It should be noted that when the voltmeter is connected to the ring side of the line under test the number of bells connected from the ring to ground can be determined by a resistance measurement. By reversing the test line, the voltmeter can be connected to the tip side of the line and the number of bells wired to it can be determined in a like manner.

In the following part on "Electrical Measurements at Toll Test Boards," the tests which can be made with a Wheatstone bridge will be described. We will, therefore, omit from this part a discussion of these tests.

It should be understood that this part is not an instruction. The No. 12 local test desk has been used as an example only with the idea in mind of drawing upon a modern test desk containing equipment of a type which can be employed in practical test work. The principles which have been discussed in the foregoing paragraphs can be applied to any desk using similar testing apparatus.

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-B

ELECTRICAL MEASUREMENTS AT TOLL TEST BOARDS

PART I

Introductory

The principles which underlie the tests made at the local Test Desk were discussed in Section IV–A. In this section we will consider the tests made at the Toll Test Board and some of the electrical principles underlying the work with which the toll testboard man comes in contact.

The tests which can be made from the No. 12 desk were described in Section IV–A in order to explain local testing methods. In a like manner the tests which can be made from the No. 4 and the No. 5 Toll Test Boards will be considered in order to explain the principles which underlie toll testing work. The principles of the tests are the same for each board so we will discuss only the tests made at the No. 4 board. We should be careful to note, also, that this section is not an operating instruction, but has for its object the explanation of the electrical principles upon which some of our testing instructions are based.

It is necessary that each part of our plant should operate in such a way that it will give the grade of service necessary to satisfy the public. However, the economies or the costs involved largely determine the way in which we build and maintain the plant. In so far as the mechanical construction of our material and apparatus goes the highest standards are used consistent, of course, with practical economies based on the use to which the material and apparatus are put. When we come to the electrical part of our work we are confronted with a different problem. Here we have a greater opportunity to select from a number of different

ways of solving our problems, one which gives us the most economical job after all things are considered. This particularly holds true in the matter of giving our subscribers satisfactory transmission. We could spend a great deal of money in making our connections talk up so loud that the persons using our telephones would be annoyed. Such a condition must be guarded against as well as the condition where the subscriber does not get good enough transmission to carry on a satisfactory conversation.

Toll service as contrasted with local service usually takes a different grade of plant facilities. This is evident when we consider that the distances covered by our toll and long distance service is considerably greater than by our local service. In Section II–E on attenuation we saw how the electrical energy received at the end of a line became smaller as the length of the circuit increased. It was also shown how leaks along the circuit affected the amount of energy that eventually arrived at the distant end. With these things in mind we can see why our toll plant is constructed and maintained to a higher standard than our local plant. This high standard makes the toll plant quite costly and it is very important that we keep it in working order just as near 100% of the time as possible so that enough business can be routed over the lines to make them pay.

The problem of keeping the lines clear and in such condition that they measure up to the transmission standards set for them depends largely upon the toll test board man. He carefully guards this costly part of our system largely by means of

tests made at the toll test boards. Not only do these tests locate troubles which make the circuit inoperative and require clearance as quickly as possible, but they also aim to detect conditions which affect transmission yet do not put the circuit completely out of order. Some of the tests give us a means whereby we can intelligently direct the outside forces to perform preventive maintenance work and still other tests check the efficiency of their work as regards the electrical part of it, i.e., proper type of transpositions, etc.

We will first consider the principles underlying the tests which can be made at the No. 4 toll test board and then take up a consideration of some of the other tests and subjects with which we are concerned.

The tests which can be made from the No. 4 board group themselves into two classes,—those involving the voltmeter and those involving the Wheatstone bridge. Let us first consider the voltmeter tests which are somewhat similar to the tests made at the No. 12 desk described in parts 1 and 2 of Section IV–A.

The standard type of voltmeter used in the No. 4 Toll Test Board has a resistance of 100,000 ohms and a central zero scale with a full scale reading of 150 volts in each direction from the zero point. See Figure 23. By operating the key which places the 1010 ohms across the terminals of the voltmeter we obtain a meter which offers 1000 ohms to the circuit in which it is placed. The meter can then be considered as a milliammeter in that the scale reading in volts is equivalent to the current flowing

in the circuit in milliamperes. The moving coil can also be used independently of the rest of the meter

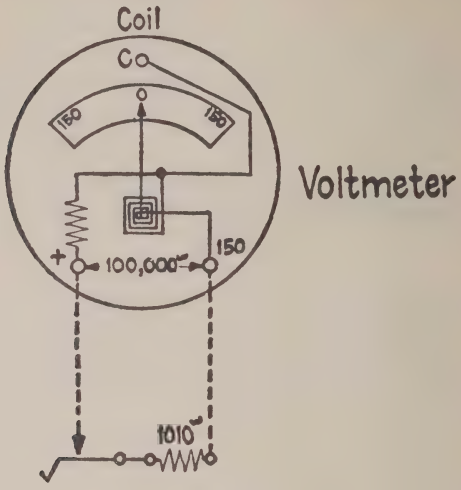


Fig. 23

circuit by connecting to posts " C " and " 150." We will describe the use of this part of the meter later. In the No. 4 board we also have a meter in one of the Morse Test circuits such as shown in Figure 24.

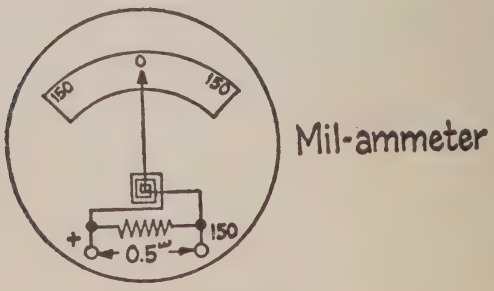


Fig. 24

It has a central zero scale with a full scale deflection of 150 milliamperes in each direction from the zero point, and offers a resistance of one-half an ohm to the circuit in which it is inserted.

In the section on local test desk work the tests which could be made with the voltmeter were described. The principles underlying those tests are exactly the same as those which underlie the tests made at the No. 4 toll test board when the voltmeter is used. However, we now have toll equipment to consider instead of exchange. Let us briefly run through the various typical tests made with the voltmeter.

Continuity Tests

When the proper keys in the testing circuit are operated the voltmeter will be connected to the line under test in series with a 150-volt testing battery as shown in Figure 25. In the example shown in this figure, we are testing a side of a phantom circuit. A deflection of the voltmeter needle will be

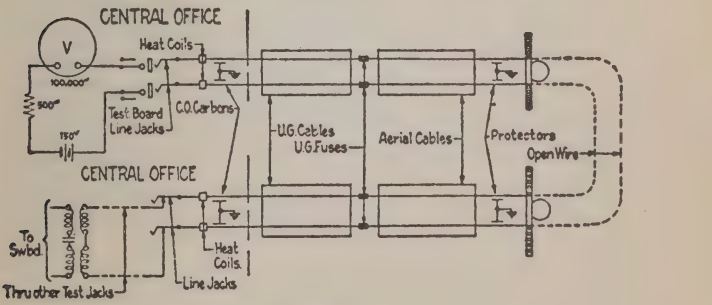


Fig. 25

obtained due to the current flowing in the circuit

which is closed through the line winding of the phantom coil at the distant office. It should be noted that in this test the testing battery is not connected to ground as was the case in the various tests made at the local test desk.

Test for Ground

In the preceding test the testing circuit was not connected to ground. In order to connect it to ground it is necessary to operate the proper keys in the testing circuit which will give us the condition

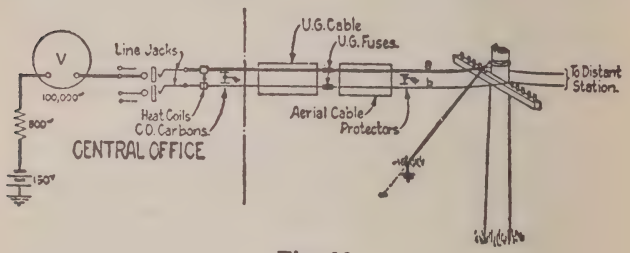


Fig. 26

shown in Figure 26. It is possible to select either the tip or the ring side of the circuit under test by the operation of the proper keys. In this example we are able to detect the ground which is caused by the line wire coming in contact with a guy. The heavy line shows the path of the current (which causes the deflection of the voltmeter needle) from the 150-volt testing battery through the voltmeter and the rest of the circuit back to the 150-volt battery.

Resistance Measurements

The voltmeter can be used to obtain resistance measurements which as a rule are used as rough

approximations to the more accurate measurements which are usually obtained with the Wheatstone bridge. As noted in Section IV–A these measurements are more accurate when the resistance of the voltmeter is nearly equal to the resistance in the external circuit which is being measured. It is

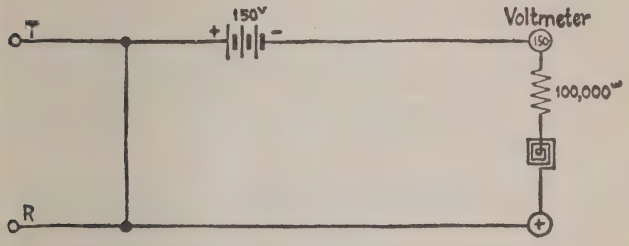


Fig. 27

important to determine the voltage of the testing battery at the time the test is made, for this voltage has a great bearing on the results obtained when calculating the resistance being measured. This can be done in the No. 4 board by operating the proper keys as shown in Figure 27 where we use the voltmeter in the board to obtain this test.

In the No. 4 board we have two meter resistances to work with—one of 1,000 ohms which should be used when measuring external resistances up to 10,000 ohms and another of 100,000 ohms which should be used for all other resistance tests.

Foreign or earth potentials will affect the voltage of the testing battery and will, therefore, affect the accuracy of the resistance measurements. The reason for this is evident when we consider that the

foreign or earth potential is in series with the testing battery as explained in Section IV–A and either increases or decreases its value depending on the polarity of the two sources of battery.

When making a rough resistance measurement a quick approximation may be obtained by the following method:

(1) Divide the resistance of the voltmeter in ohms by the reading of the voltmeter in volts. Then each volt will represent a certain number of ohms.

(2) Next subtract the reading of the voltmeter from the voltage of the testing battery.

(3) Multiply the number of volts obtained in (2) by the number of ohms per volt obtained in (1) and the product will equal the resistance being measured.

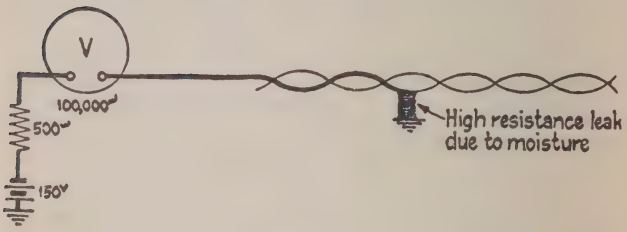


Fig. 28

For example, in Figure 28 we have a circuit which let us say, measures 75 volts. The testing battery measures 150 volts. Let us determine the resistance of the line from the Central Office through the leak to ground.

Since the resistance of the voltmeter is 100,000 ohms we have:

(1) 75 (voltmeter reading) = 100,000 (resistance in ohms of voltmeter).
Therefore, 1 volt scale deflection = 1,333 ohms.

(2) 150 (voltage of testing battery) — 75 = 75.

(3) 1,333 × 75 = 99,975 ohms.

In order to obtain a more exact calculation of resistance, we should use the formula which gives the following relation:

$$X = \frac{rE}{D} - r - r'$$

Where X = the resistance under test,
r = the resistance of the voltmeter,
E = the voltage of the test battery,
D = the voltmeter reading when in series with resistance X and the testing battery,
r = the resistance in series with the testing battery.

When the resistance of the voltmeter is 1,000 ohms the 500-ohm resistance which is in series with the testing battery must be considered. However, when the resistance of the voltmeter is 100,000 ohms, the 500-ohm resistance may be neglected thereby causing only a small error.

Let us compute the resistance of the line illustrated in Figure 28 using the information given above.

$$X = \frac{100{,}000 \times 150}{75} - 100{,}000 - 500 = 99{,}500 \text{ ohms}$$

or in case we neglect to consider the 500-ohm resistance X would then equal 100,000 ohms.

We will note that the external resistance obtained by the formula when the 500-ohm value was not included in the calculation differs by only 25 ohms from the result obtained by the rough method. When the 500-ohm resistance was included the difference became greater, namely, 475 ohms.

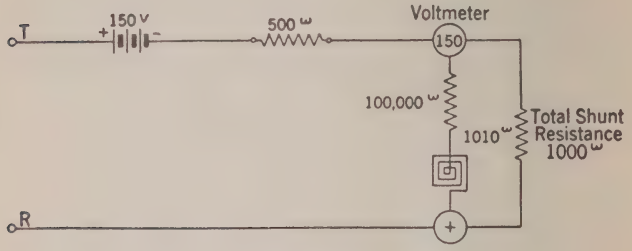


Fig. 29

Figure 29 shows the testing circuit obtained when the voltmeter offers 1,000 ohms resistance to the circuit under test. Let us assume we have this circuit set up and the reading is 75 volts as before. The resistance **X** will, however, be considerably different from the value we obtained above. We will assume that the testing battery is 150 volts as in the other test.

$$X = \frac{1{,}000 \times 150}{75} - 1{,}000 - 500$$

or $X = 500$ ohms which would be the resistance of the circuit under test.

It should be noted that in this case the 500-ohm resistance **must be included** in the calculation, otherwise we would have a serious error. In the case which we first considered, an error of 475 ohms is only a small percentage of the total when the

total is of the order of 100,000 ohms; whereas, in the last case an error of 500 ohms would represent a very high percentage error.

Insulation Resistance and Leakage

The voltmeter finds one of its greatest uses on the No. 4 board in making "insulation" tests. We have already considered the reason why it is particularly necessary in the case of toll lines to have them built and maintained to a high standard of insulation. In order to tell whether they meet this standard, we must resort to electrical tests. In Section IV–A we considered these tests in a brief way. We will now take up in more detail the principles underlying them.

Figure 30 shows the circuit obtained when a test is made on one wire of a toll circuit. 150 volts is impressed on the line under test through the

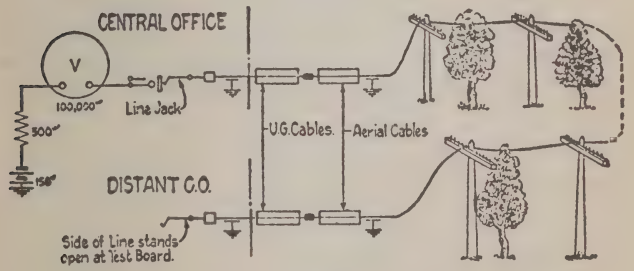


Fig. 30

100,000-ohm voltmeter. As previously mentioned it is necessary to have the voltmeter resistance approximately equal the resistance which we wish to measure in order to obtain accurate results. Our toll lines usually have a higher insulation resistance

than 100,000 ohms. Therefore, this resistance value of the voltmeter should be used when making insulation tests.

It should be noted that the leaks to ground and also across the pair occur along the entire length of the circuit; defective insulators; bad trimming conditions; leaky cable pairs; leaks at the open space cut-outs; all these things tend to cause leaks through resistances which vary with each particular case. Since it is impracticable to divide the line into small sections (however, this is necessary under some conditions when running down trouble) we take the over-all measurement between two test stations and apportion the leakage resistance equally among the various miles of circuit and thus obtain a measurement of the insulation resistance per mile of circuit. It is possible that such a procedure might be misleading in that the greater portion of the low insulation could be concentrated at one bad spot on a long line. We must be careful to guard against such conditions by detecting them either by means of line inspections or by more elaborate electrical tests.

Let us assume, however, that the leaks are distributed in a fairly uniform manner along the entire line and then let us further consider the leaks for each mile of line concentrated at the middle point of the mile section. Figure 31–A shows the way these conditions would appear in a circuit diagram. Here we have a network made up of a large number of resistances connected in series-parallel.

The series resistances R_1, R_2, etc., represent the series resistance of the line and are so low in com-

parison with the shunt resistances to ground represented by the leaks L_1, L_2, etc., that they can be

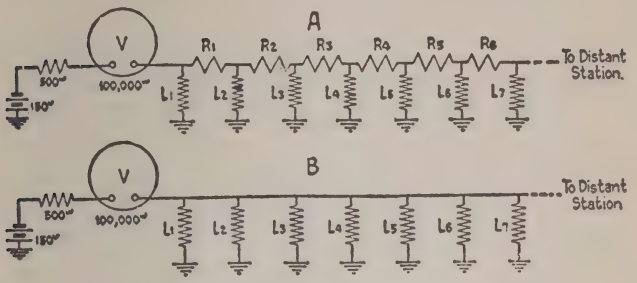


Fig. 31

neglected in the following calculation without seriously affecting the result. The network can be simplified as shown in Figure 31–B. Here we have a great number of parallel paths in a circuit which can be further simplified as shown in Figure 32. It

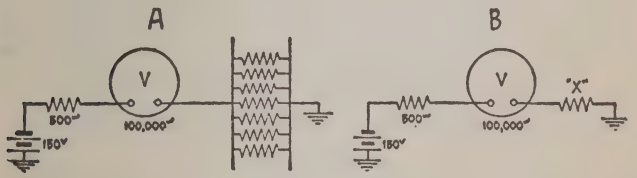


Fig. 32

should be noted that the greater the number of paths the smaller the resistance **X** becomes. **X** may also be reduced by having one of the paths low in comparison with the others.

From the foregoing we should plainly see that as the length of the circuit under test increases we can look for a greater deflection of the voltmeter

needle which is caused by lowering the value of **X**.

Let us see how we can determine the insulation resistance of an isolated line which is tested by being connected to another line which in turn appears at the test board. See Figure 33. Here the line from office **B** to **C** is being tested by being

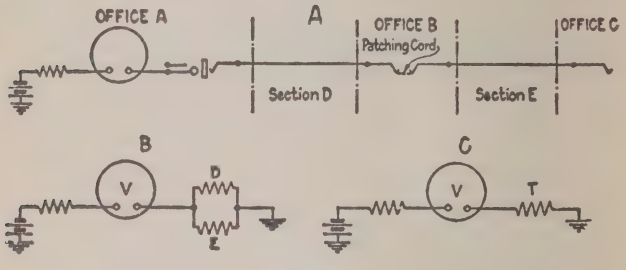


Fig. 33

patched to a line from **A** to **B** which is accessible to the test board man at **A**. It should be noted that the insulation resistance of the section from **B** to **C** is in parallel with that of the section from **A** to **B** and not in series with it. For this reason it is not possible to take the voltage reading obtained when testing the over-all circuit from **A** to **C** and subtract from it the voltage reading obtained from the test made on the circuit from **A** to **B** and obtain a value which can be applied to the calculation of the insulation resistance of the section from **B** to **C**.

As shown in Figure 33–B the insulation resistance of Section **D** is in parallel with that of Section **E**, and combines with it to make a resultant resistance **T** as shown in 33–C. According to the calculation of parallel resistances discussed in Section I–C we have:

$$T = \frac{D_r \times E_r}{D_r + E_r}$$

T is determined from the voltage reading obtained in the over-all test. **D** can likewise be determined from the test of Section **A–B**. Therefore, to obtain the insulation resistance of **E** we must proceed as follows:

$$T(D_r + E_r) = D_r \times E_r$$
$$TD_r + TE_r = D_rE_r$$
$$TD_r = D_rE_r - TE_r = E_r(D_r - T)$$

$$\frac{TD_r}{D_r - T} = E_r$$

which gives the insulation resistance of the Section **E**.

In our tests so far we have obtained the insulation resistance of the entire length of a circuit. To obtain the insulation resistance per mile of circuit we simply have to multiply the value **X** by the length in miles of the circuit under test, since all the leaks are considered to be uniform and in parallel.

Let us now calculate the insulation resistance of the line shown in Figure 30.

The formula which will be used was given in Section IV–A, and is

$$X = \left(\frac{E}{D} - 1\right)100{,}000$$

Where X = the resistance being measured,
E = the testing battery voltage,
D = the voltmeter reading when in series with resistance X and the testing battery,
100,000 = the resistance of the voltmeter in ohms.

Let us assume the line is 100 miles long and that the meter reads 50 volts when the line is up on test. The testing battery tests 150 volts.

$$\text{Then, } X = \left(\frac{150}{50} - 1\right)100{,}000,$$

$$X = (3 - 1)100{,}000$$

$$X = 2 \times 100{,}000 = 200{,}000 \text{ ohms,}$$

and the insulation resistance per mile equals $200{,}000 \times 100 = 20{,}000{,}000$ or 20 megohms.

We have previously mentioned that it is important to consider the voltage of the testing battery when calculating the value **X**. Let us assume the voltage of the testing battery is 130 volts instead of 150.

$$X \text{ then equals } \left(\frac{130}{50} - 1\right)100{,}000,$$

$$\text{or } (2.6 - 1)100{,}000,$$

$$\text{or } 1.6 \times 100{,}000 = 160{,}000 \text{ ohms,}$$

and the insulation resistance per mile equals $160{,}000 \times 100 = 16{,}000{,}000$ or 16 megohms.

The foregoing discussion concerned itself chiefly with the insulation resistance to ground, or, expressed in another way, the leakage to ground. There also exists a leakage between wires of a pair which affects our circuits to a very marked degree and with which we are greatly concerned. The same general principles underlie the calculation for this mutual insulation resistance as for the insulation resistance to ground and the formula used in the preceding paragraph can be applied to calculate the insulation resistance between the two wires of the pair.

To obtain this mutual insulation resistance it is

necessary to open the wires of the pair at the distant end and connect them to the testing circuit when the keys are operated to give the set-up shown in Figure 34.

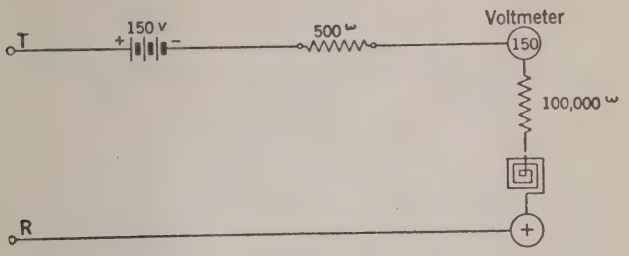


Fig. 34

Tests for Crosses

In Section IV–A we saw that crosses are considered as falling into two classes: (1) those between the wires of a pair commonly known as " short circuits; " and (2) those between either wire of a pair and another circuit.

Short circuits can be detected by means of tests made when the line under test is connected to the test circuit as set up in Figures 29, 34, 35 or 36. If a low resistance is obtained in these tests it is an indication that the line under test is short-circuited.

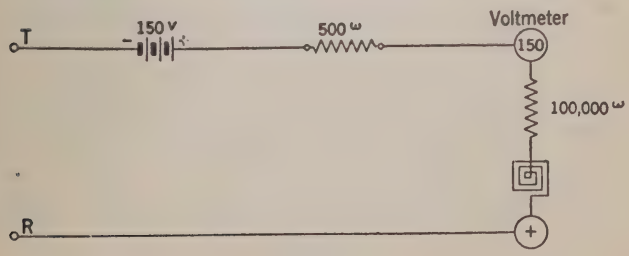


Fig. 35

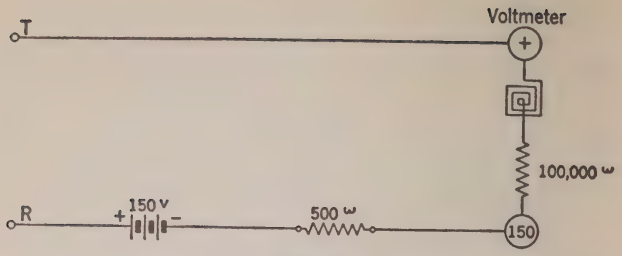


Fig. 36

The crosses of class (2) are more difficult to detect. If the line under test is crossed with a circuit that is connected to ground or battery, it is comparatively easy to detect this trouble by means of the testing arrangement shown in Figure 37 or

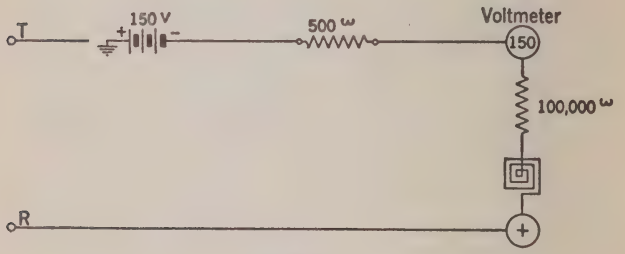


Fig. 37

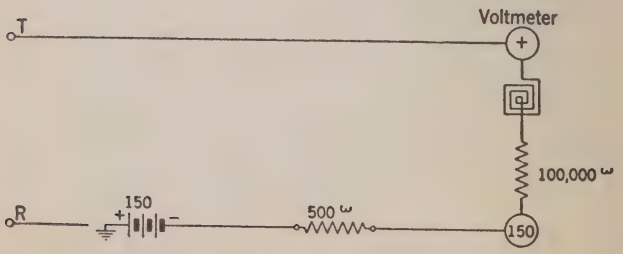


Fig. 38

38. However, if it is crossed with a conductor or line which is not connected to ground or battery, other means of detecting this trouble must be employed. We can resort to tests which indicate unbalances to obtain a test which will show up the cross. It is also possible to detect these crosses by means of listening tests. These tests will be discussed later.

Tests for Foreign or Earth Potential

The method of obtaining a test for foreign or earth potential is similar to that shown in Figure 15 in Section IV–A. The voltmeter is either connected across the tip and ring of the testing circuit as shown in Figure 39, or it is connected to either side of the line under test and directly to ground without any testing battery in the circuit. Such a testing scheme allows us to use the voltmeter to

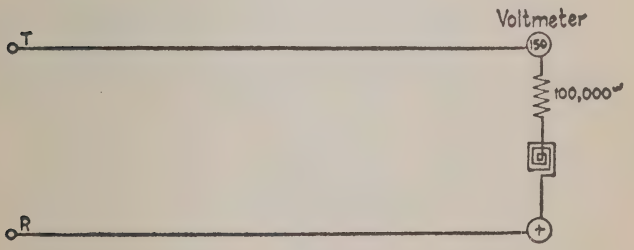


Fig. 39

measure voltage in a manner similar to that used in measuring voltage with a portable meter. By considering the principles underlying the tests made with portable meters, which we use to a great extent in our everyday work, we can explain practically all of the tests made from our test boards.

The test boards, it is true, have a somewhat elaborate arrangement of apparatus—all, however, necessary—but when a particular testing set-up is sketched in schematic form with the circuit stripped of its many seemingly complex paths, we sometimes wonder at the simplicity of it all.

Capacity Tests

In the preceding section we went into a somewhat lengthy discussion of capacity tests. The same principles hold in similar tests made from the toll test board. Instead of having subscriber apparatus to deal with, we have, on the other hand, the capacity of lines and the capacity of some central office apparatus employing condensers to consider. However, capacity action is the same in so far as our direct current tests are concerned, regardless of how it presents itself.

Let us first consider the capacity tests of a side circuit of a phantom as shown in Figure 40. In this circuit, when we first connect our testing circuit, as shown in Figure A, the condenser takes on a

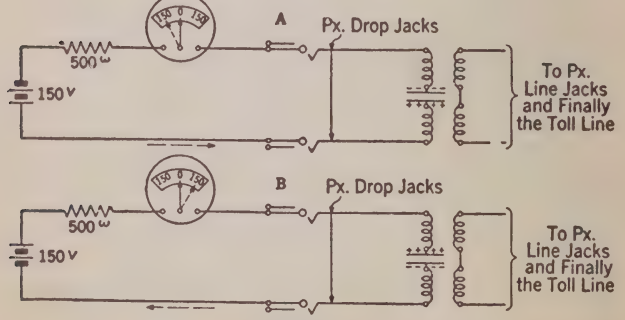


Fig. 40

charge as indicated and the voltmeter needle "kicks" across the scale as shown. When the battery reversing key is thrown, the charge on the condenser is reversed and another pulse of current rushes through the voltmeter in the direction shown, which causes the needle of the voltmeter to "kick" across the scale in the opposite direction to that shown in sketch "A." The larger the capacity of the condenser the greater will be the deflection or throw of the needle. By determining the deflection caused by different known amounts of capacity, we can tell the unknown amount of capacity in series with the circuit under test from the throw of the voltmeter needle.

Capacity of lines present a little different condition from that of fixed condensers. Figure 41–A shows a pole pin pair of wires and the capacity

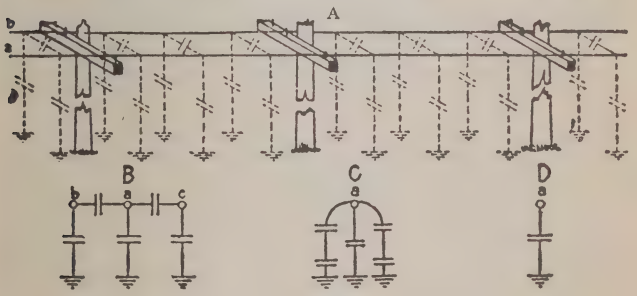


Fig. 41

action existing between the wires of the pair and ground. Figure 41–B shows an end view of this pair and another wire **c** which is on the pin adjacent to wire **a**. We can see from this sketch that throughout the entire length of the wires **a** capacity effect is present. We might consider this

capacity made up of a large number of small condensers, all in parallel, and show their resultant effect as concentrated at one spot, as indicated in "B." This effect can be considered as combining in the manner shown in "C" and finally as shown in "D." We should be careful to note that the actual capacity effect is distributed along the entire length of the line and it is only to bring out the effect on the voltmeter tests that we shall consider this capacity lumped at one point. We are neglecting any other effects of the line which must be considered in transmission problems, i.e., resistance, inductance, etc.

In our tests of the various line wires let us consider the capacity to ground as shown in Figure 41–D. The wires in a cable can be treated in the same way as the open wire just described, for capacity action is also present in cable to a marked degree. Figure 42 shows a test of a wire which is open at the distant end. When the circuit shown

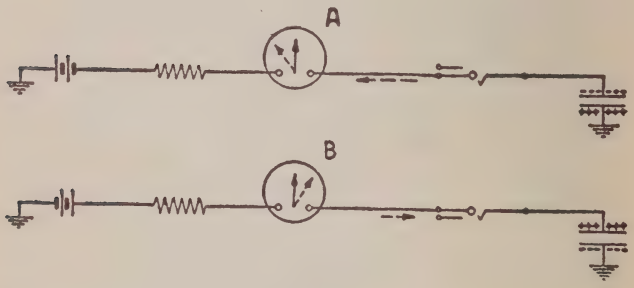


Fig. 42

by "A" is established, the condenser (which represents the accumulated effect of the entire length

of the side of the circuit) takes a charge as shown and causes the needle of the voltmeter to "kick" across the scale in the direction indicated. When the testing battery is reversed the charge on the condenser is reversed and the current which flows momentarily causes the needle of the voltmeter to "kick" across the scale in the opposite direction as shown. The length of the line particularly affects the amount of capacity present. Therefore, different lines will give different deflections of the needle. However, each wire of a pair or a phantom group should give the same deflection.

In the paragraph above under insulation resistance we saw that the wires of a circuit have a mutual effect as well as one to ground. This also holds true in regard to capacity effects. However, in the tests described in this section we are mainly concerned with the capacity to ground of the wires of a circuit and we will not discuss this mutual effect.

Let us now see what happens when one side of a pair becomes crossed with another wire which in

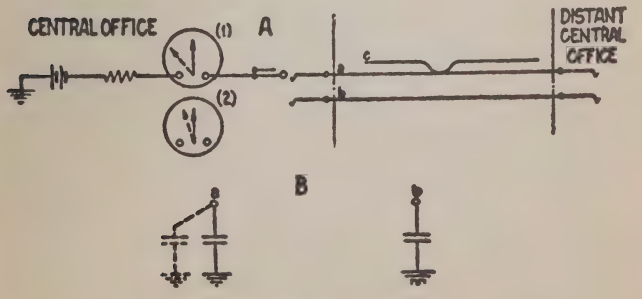


Fig. 43

turn is clear of grounds. Figure 43 " A " shows a line under test, one side of which is crossed with a dead length of wire c. By a voltmeter test this cross can be detected. The deflection (1), obtained when wire a is tested, is considerably greater than the deflection (2), obtained when wire b is tested. The reason for this is evident when we consider sketch " B " where the capacity from wires a and b to ground are indicated by the condensers in full lines. These we will note are of the same value. However, the capacity of wire c is in parallel with that of wire a and is indicated by the condenser in dotted lines which we will note is in parallel with the condenser in full lines, thereby giving a resultant condenser of greater capacity than that associated with wire b. In the paragraph above we saw that the deflection of the voltmeter depended upon the capacity of the condenser under test. For these reasons we get a greater deflection of the needle for wire a which gives us the indication of trouble.

In telephone practice we use the receiver very frequently as a testing instrument. The inside man " shoots " most of his trouble with the help of a set of " picks." The receiver is a very sensitive instrument which will indicate the flow of a minute current. Therefore, if it is connected across any two points which have a difference of potential (direct current source), it will indicate this fact by giving a " click." The loudness of this " click " gives an indication of the amount of battery or the drop in voltage between the two points. When an alternating current flows through the receiver a steady tone is given off. In one of the preceding paragraphs above which described the tests for crosses,

reference was made to the use of the receiver for detecting crosses which did not show up on the voltmeter. Figure 44 shows a circuit which is ob-

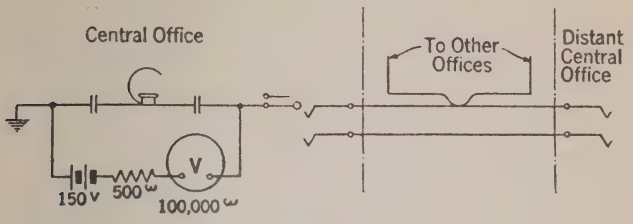


Fig. 44

tained when the proper keys are operated in the No. 4 toll test board. In this case the receiver in series with two condensers is cut across the voltmeter and testing battery and will indicate a greater volume of noise when connected with wire **a** than when connected with wire **b**.

In Part 2 of this section the discussion of the measurements made at the toll test board will be continued. In this part a description of the Wheatstone bridge tests will be given.

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-B

ELECTRICAL MEASUREMENTS AT TOLL TEST BOARDS

PART II

In Part 1 of this section a description was given of the voltmeter tests made at the No. 4 toll test board. These tests are chiefly intended to indicate in a rapid way the nature of a fault. It should be noted, however, that certain routine tests, as, for instance, "insulation tests" use the voltmeter as a testing instrument. In this part we shall discuss the tests made with the Wheatstone bridge. These tests determine not only the location of a fault but also any unbalances that might exist in a pair of conductors or a phantom group in so far as direct current tests can indicate.

Before discussing the actual use of the Wheatstone bridge in testing work let us first consider some of the things that the toll test board man must take into account if he is to do a real job in giving the lineman accurate locations of trouble or in keeping the circuits in good working order in so far as electrical tests can help.

The Wheatstone bridge as explained in Section I–E is an instrument which measures resistance. In the No. 4 toll test board we use the bridge for an additional purpose; namely, that of measuring capacity. We are chiefly interested (in so far as the tests which will be described in this part are concerned) with the resistance and capacity of our circuits. Some of the things which govern these characteristics are, the kind of conductor, whether copper or iron or other metal, its length and gauge, whether open-wire or in cable either loaded or non-loaded, the resistance in joints and connections, either in the office or the outside plant, and the temperature.

Figure 45 gives an idea of the numerous places where we might find defective conditions in a cir-

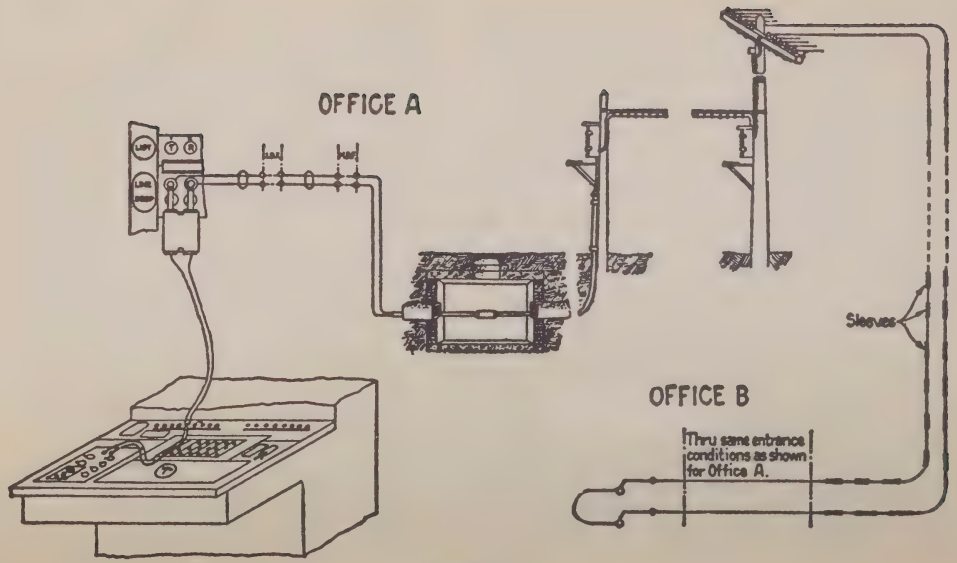

OFFICE A
Sleeves
OFFICE B
Thru same entrance conditions as shown for Office A.

Fig. 45

cuit. Follow this circuit through from the Wheatstone bridge to the short-circuit plug at the distant office and see the many places that a high resistance joint or connection might creep in to affect the proper resistance of the circuit. The plug on the testing cord might be dirty and offer an appreciable resistance, some of the many connections in the Central Office might be poorly soldered, the joints in the splices in the cable might have resistance, the cross wires under the washers at the cable boxes might not be clean and the nuts, together with the associated lock nuts, might not be properly tightened, the bridles at the dead end pole might be poorly connected to the aerial cable lugs and to the line wire, any one of the hundreds of sleeves in the line might have high resistance, and so on, until finally we arrive at the short-circuit plug at the distant office. Here is one more example which shows that the telephone job depends upon the individual, for each particular unit of plant that he has occasion to work on must be left in a perfect condition in order to have the system give good service.

In order to locate trouble accurately the test board man must have suitable records which will give, for the various circuits, information about their makeup. These records should give information concerning the electrical characteristics of the circuit such as the length and gauge of the conductors, information concerning irregularities in construction, and the resistance and capacity of the various parts of the circuit such as the portion in the terminal cables and intermediate cables. They should also give such information as the location of cable boxes, test stations, pole numbers near railroad stations or road crossings, junction points and

other items which might be of assistance in directing the lineman to the fault.

Figure 46 shows the circuit of the Wheatstone bridge used in the No. 4 board. The bridge is of the inverted dial type with sliding contacts having two ratio arms and four groups of adjustable resistances in the rheostat arm. It has three adjustable resistances designated **A**, **B** and **R**. The resistances **A** and B are known as the ratio arms and have four coils each of which have resistances of 1, 10, 100 and 1,000 ohms respectively. The resistance **R** represents the rheostat arm and has four adjustable resistances of 10 coils each which are designated units, tens, hundreds and thousands. These resistances may be adjusted to give a total resistance in series of from 1 to 11,110 ohms.

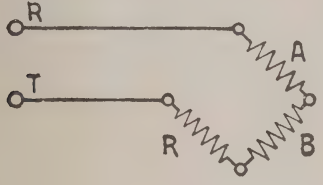
The maximum allowable power consumption in any arm of the bridge is 1 watt, that is, if 150 volts were impressed across an arm the allowable current in that arm would be 6.6 milliamperes.

The galvanometer is provided with a shunt for reducing the magnitude of the deflection and to protect the galvanometer against injury from excessive currents. In making the preliminary balance the shunt should first be set at .001 and changed when a balance is obtained to .01 then .1 and finally to "open." If the needle fluctuates the galvanometer should be shunted sufficiently to keep the needle within a range of two points in either direction from zero.

In Section I–E the theory of the Wheatstone bridge was described. In the following paragraphs this knowledge will be assumed and only the tests which are made with the bridge will be discussed.

Wheatstone Bridge as a Rheostat

Very frequently it is necessary to terminate a toll line with a resistance of a definite number of ohms or to obtain for other tests a definite resistance. This is possible in the No. 4 board by the proper operation of keys which gives the circuit shown in



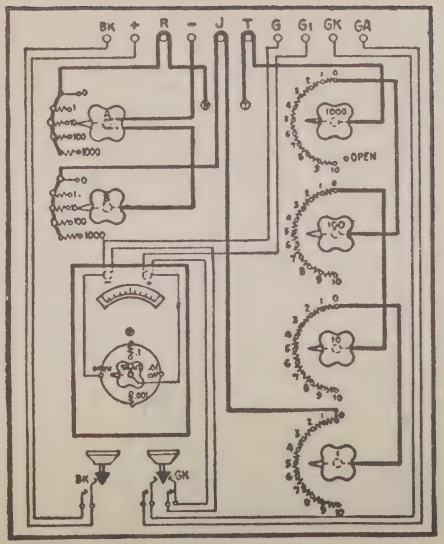
Wheatstone Bridge used as adjustable resistance

Fig. 47

Figure 47. The resistances in the **A**, **B** and **R** arms are in series and can be varied to give the desired value. Thus, by having the **A** arm on 100, the **B** arm on 100 and the **R** arm on 500, we would have a total resistance of 700 ohms across the tip and ring of the testing circuit.

Loop Resistance

In Part I of this section we have seen how the voltmeter can be used to determine the resistance


BK
+
R
-
J
T
G
G1
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GA
1000
OPEN
100
10
1
.1
.01
.001
BK
GK

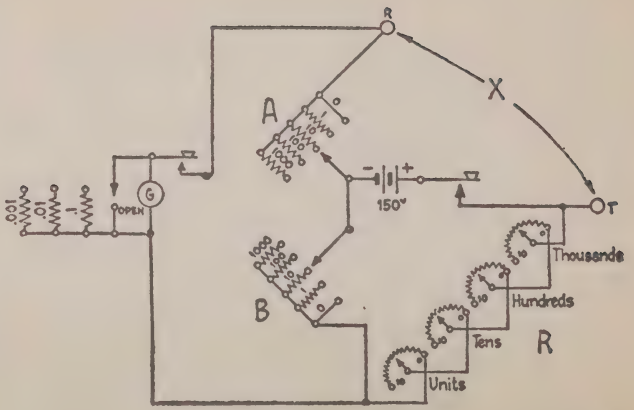
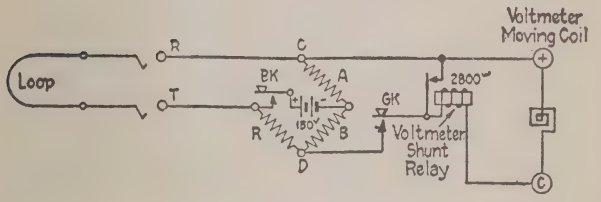

R
X
A
B
G
OPEN
.001
.01
.1
150v
T
Thousands
Hundreds
Tens
Units
R

Fig. 46

of a circuit. The value obtained in this manner is usually a rough approximation and when accuracy is desired a more precise test using the Wheatstone bridge should follow the voltmeter test.

In the description of the voltmeter used in the No. 4 board mention was made of the moving coil of the meter being available for test purposes. This portion of the voltmeter (see Figure 23) gives us a form of galvanometer which is not as sensitive as

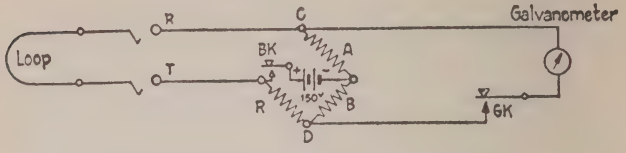


Loop resistance measurement using voltmeter moving coil and shunt relay in place of Galvanometer.

Fig. 48

the galvanometer in the Wheatstone bridge. However, it affords a means of obtaining a quick rough balance preparatory to the more exact balance obtained with the galvanometer of the Wheatstone bridge. Figure 48 shows the circuit obtained when the proper keys are operated in the No. 4 board. Reference will be made later to the loop test which is illustrated in this sketch. The part of the sketch to consider at this time is the circuit from **D** through the galvanometer key **GK**, the voltmeter shunt relay, the voltmeter moving coil and back to **C**. Note that when the current through the relay is great enough to cause injury to the moving coil the armature pulls up and shorts out this coil. In

Figure 48 we will observe that the voltmeter moving coil with its shunt relay takes the place of the galvanometer shown in Figure 49.



Loop resistance measurement using Galvanometer.

Fig. 49

Figure 43 shows a typical setup of a circuit whose loop resistance is being measured. The Wheatstone bridge at the test station is connected to the circuit as shown and a "short-circuit" plug is placed in the jacks at the distant end of the circuit. It is, of course, possible to illustrate the test if the "short" is placed at any point along the line. One thing of great importance to consider is that the resistance of the "short" affects the test. We will illustrate this fact later. Figures 48 and 49 show a schematic of the circuit shown in Figure 45. To obtain the resistance of the conductor from **R** to **T** the bridge must be balanced as described in Section I–E on measuring instruments.

It is desirable when making the preliminary balance to have the ratio arms **A** and **B** equal. To secure the best results the resistances of **A** and **B** should be as near in value as possible to the resistance being measured. Loop resistances are, however, usually measured with the ratio arms **A** and **B** set at 1,000 ohms. The resistance measurements will then be correct to within 1 ohm. If a

balance can not be obtained with equal ratio arms or if a very accurate measurement is desired, unequal values should be used in the ratio arms. The instructions with each bridge give the best values to be used in the **A** and **B** arms for the particular value of the resistance **X** which is being measured.

Let us now calculate the loop resistance of the circuit shown in Figure 45. The following formula will be used.

$$X = \frac{A}{B} R \qquad (1)$$

Where X = The loop resistance of the circuit under test
A = The value of the resistance in arm **A**
B = The value of the resistance in arm **B**
R = The value of the resistance in the rheostat arm.

Let us assume that arms **A** and **B** are set at 1,000 ohms and a balance is obtained when **R** is 400 ohms. By substituting these values in the formula given above we have

$$X = \frac{1{,}000}{1{,}000} \times 400 = 400$$ ohms, the loop resistance of the circuit shown in Figure 45.

It should be noted that when the ratio arms are equal the resistance **X** equals the resistance in **R**.

If the ratio arms are unequal the value of **X** will be either greater or less than **R**, dependent upon the fraction $\frac{A}{B}$

Let us assume in the above test that **A** was set at 100, B at 1,000 and R at 4,000.

Then $X = \frac{100}{1{,}000} \times 4{,}000 = 400$ ohms, the loop resistance of the circuit shown in Figure 45.

This value gives the resistance of the conductors if the "short" does not have resistance. Figure 50–A shows a pair of wires under test which are "short-circuited" at **C–D**. We will assume that they have a uniform resistance throughout their

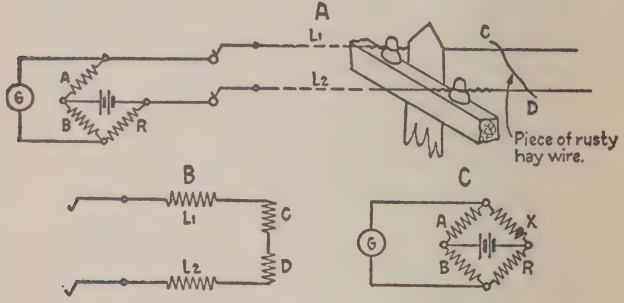


Fig. 50

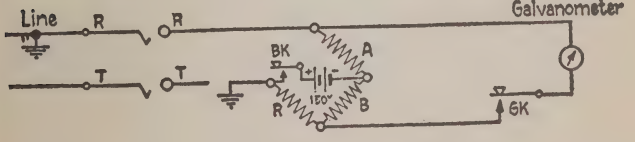
entire length. Due to the poor connection between the conductors and the hay-wire a resistance is introduced at **C** and **D** which is shown in sketch **B** where L_1 and L_2 indicate the resistance of the line wires. Sketch **C** shows a schematic of the Wheatstone bridge circuit obtained in this test. **X** represents the resistance being measured. Let us assume that in this case our calculation gives **X** equal to 200 ohms. We can see that the 200 ohms can not be used in determining the distance to the fault although the resistance of a circuit mile of

the wire is known. If the resistances **C** and **D** were known they could be deducted from the value of **X** and the distance to the fault determined. The temperature at the time the test is made would have to be considered in calculating this distance.

A "short" given by a lineman if not put on with care could contain resistance and give a condition such as illustrated above which would result in not obtaining a true value of the line resistance. Dirty plugs at the distant office could also give a similar condition. Since we are concerned only with the resistance of the conductors of the circuit in tests such as described above we must always be careful that the incidental work we do in order to obtain the tests does not introduce errors which are liable to cause a lineman to needlessly travel miles out of his way to find the trouble.

Single Wire Resistance Measurements

It is frequently necessary to obtain the resistance of a single wire of a circuit. This test can be made under favorable conditions in the manner shown in Figures 51 and 52. The wire under test is grounded

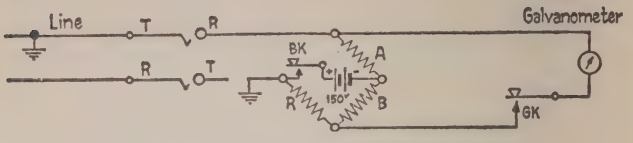


Single grounded wire resistance measurement.

Fig. 51

at the point to which it is desired to obtain its resistance. However, the results obtained by this

method are not very reliable. Foreign or earth potentials, if present, are liable to make it difficult to



Single grounded wire resistance measurement.

Fig. 52

obtain a balance with the galvanometer. In such a case better results may be obtained by using the voltmeter moving coil. The resistance obtained by this ground method includes the resistance of the ground and the ground connection at each end of the line.

When two wires are available the resistance of either of them may be determined by measuring their loop resistance and then making a Varley or Murray loop test as described later with the two wires grounded at the distant station.

If three wires (or what is more likely the four wires of a phantom group) are available the resistance of any one of the three or four may be determined as follows: See Figure 53. The four wires are connected together at the point to which the resistance is to be measured. A loop resistance is

Fig. 53

then taken of wires a and b, a and c, b and c, and c and d. Each of wires a, b and c has now been measured twice. Evidently one-half the sum of the three loop resistances equals the sum of the resistances of the three wires, a, b and c, and the resistance of any one wire is the difference between this resistance and the loop resistance of the other two. The resistance of wire d can be obtained by subtracting the resistance of wire c from the loop resistance of cd.

This may be expressed in the following formula.

$$R_a = \frac{R_{ab} + R_{ac} + R_{bc}}{2} - R_{bc} \qquad (2)$$

$$R_b = R_{ab} - R_a \qquad (3)$$

$$R_c = R_{ac} - R_a \qquad (4)$$

$$R_d = R_{cd} - R_c \qquad (5)$$

Where:

R_a = resistance of wire a.
R_b = resistance of wire b.
R_c = resistance of wire c.
R_d = resistance of wire d.
R_{ab} = loop resistance of wires a and b.
R_{ac} = loop resistance of wires a and c.
R_{bc} = loop resistance of wires b and c.
R_{cd} = loop resistance of wires c and d.

For example, suppose the loop resistance of wires a and b = 210 ohms, a and c = 240 ohms, b and c = 250 ohms and c and d = 230 ohms. Then $R_{ab} + R_{ac} + R_{bc} = 210 + 240 + 250 =$ 700 ohms and $\frac{R_{ab} + R_{ac} + R_{bc}}{2} = \frac{700}{2} = 350$ ohms.

$R_a = 350 - 250 = 100$ ohms
$R_b = 210 - 100 = 110$ ohms
$R_c = 240 - 100 = 140$ ohms
$R_d = 230 - 140 = 90$ ohms

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-B

ELECTRICAL MEASUREMENTS AT TOLL TEST BOARDS

PART III

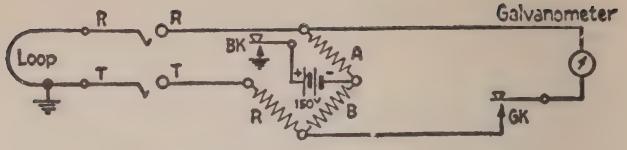
Varley Loop Test

In the previous paragraphs we saw that it is impossible to secure an accurate location of trouble when the resistance of the fault is included in the circuit at the time the resistance is measured. Therefore it is necessary to have some means of locating the fault that is independent of the resistance of the fault. Such a means is given in the Varley loop test. In making this test a good wire should be available which preferably should be the mate of the bad wire. However, if the mate is not available a wire of the same length, gauge and conductivity as the bad wire should be used. In making locations in cable, the good wire should be the mate of the bad wire or a wire in the same layer of conductors, otherwise some inaccuracy may result on account of the difference in actual length due to the twist in the layup of the cable. Where the cable pairs are loaded it is necessary to have the same number and type of load coils on the good wire as on the bad.

The insulation to ground of the good wire should be at least 100,000 ohms to secure an accurate Varley test.

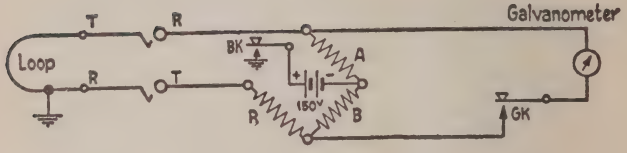
Figures 54, 55 and 56 show in schematic form the Varley loop set up.

It should be particularly noted that the fundamental Wheatstone bridge circuit is obtained in these setups. For instance, in Figure 54 the grounded side of the battery is extended through the earth to the point on the line where the



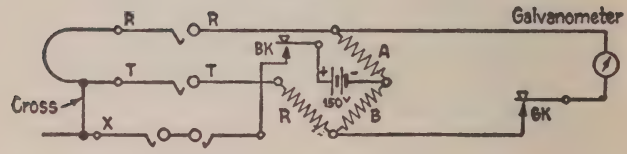
Varley loop test.

Fig. 54



Reversed Varley loop test.

Fig. 55



Metallic Varley test.

Fig. 56

"ground" exists. The **X** arms then include the resistance of the ring conductor from the testing station to the distant office (through the short) and the part of the tip conductor from the distant office to the fault. The **R** arm not only includes the resistance in the variable resistance **R** but also the resistance of the tip conductor from the testing station to the fault.

Figure 57–A shows the circuit obtained when the bridge is connected to a line which is grounded on

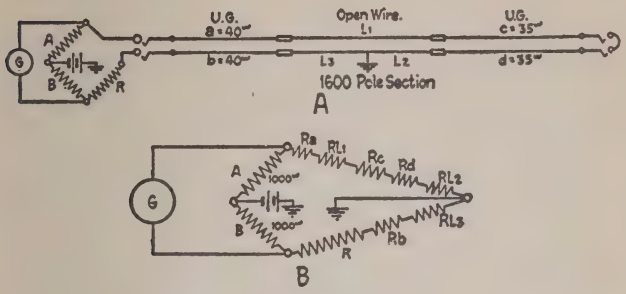


Fig. 57

one side and the proper keys have been operated to give a Varley loop test.

After the short has been placed at the distant office a loop resistance, which has been previously described, should be taken. This is done so that the resistance of a circuit mile or a pole section of the conductors may be obtained for the particular time at which the location test is being made. It will therefore be unnecessary to consider the effect of temperature on the resistance of the line wires.

Following the loop test the circuit is set up as shown in Figure 57–A with each of the ratio arms **A** and **B** set at either 100 or 1,000 ohms. It should be noted that the grounded wire is connected to the **R** arm of the bridge. This is necessary in order to obtain a balance. By considering the formulæ which follow this will be evident.

We will assume that the test board man has a

record of the resistance of the cable conductors at both the near and far ends of the line and also the number of pole sections of open wire in the line.

Figure 57–B shows a schematic of the circuit obtained in this test. Here we can see how the fundamental Wheatstone bridge circuit is obtained. The ratio as explained in Section I–E is

$$\frac{A}{B} = \frac{R_a + R_{L_1} + R_c + R_d + R_{L_2}}{R + R_b + RL_3} \qquad (6)$$

where the R factors with their subscript letters represent the resistance of the various portions of the circuit as shown in the sketch.

$$\text{Since } \frac{A}{B} = \frac{1{,}000}{1{,}000} = 1$$

$$\text{we have } R + R_b + R_{L_3} = R_a + R_{L_1} + R_c + R_d + R_{L_2} \qquad (7)$$

From the loop test and the record which contains the value of the resistance of the cable conductors we can determine the loop resistance of the open wire. This is done by subtracting the total loop resistance of the near and far-end cables from the overall loop resistance.

We will assume that each wire of the pair has the same resistance, therefore one side of the pair L_1 will have one-half the loop resistance of the open wire. L_2 and L_3 together form the other side of the pair, therefore

$$R_{L_2} + R_{L_3} = R_{L_1} \qquad (8)$$

$$\text{or } R_{L_2} = R_{L_1} - R_{L_3} \qquad (9)$$

Substituting this value in equation (7) we get

$$R+Rb+R_{L_3}=R_a+R_{L_1}+R_c+R_d+R_{L_1}-R_{L_3} \quad (10)$$

$$\text{or } 2\ R_{L_3}=R_a+2\ R_{L_1}+R_c+R_d-R-R_b \quad (11)$$

R_a and R_b should be equal on account of being sides of the same pair. They therefore cancel in equation (11). $2RL_1$ equals the loop resistance of the open wire. Since $R_c + R_d$ equals the loop resistance of the cable cd and $2RL_3$ equals the loop resistance of the open wire to the fault, we have

$$2\ R_{L_3}\left\{\begin{matrix}\text{loop resist-}\\\text{ance of open}\\\text{wire to fault}\end{matrix}\right\}=R_{ow}\left\{\begin{matrix}\text{loop resist-}\\\text{ance of}\\\text{open wire}\end{matrix}\right\}+R_{cd}\left\{\begin{matrix}\text{loop resist-}\\\text{ance of dis-}\\\text{tant cable}\end{matrix}\right\}-R \quad (12)$$

Since the loop resistance of the open wire plus the loop resistance of the distant cable equals the overall loop resistance minus the loop resistance of the near-end cable we have an equation that gives the same value as (12) namely.

$$2\ R_{L_3}\left\{\begin{matrix}\text{loop resist-}\\\text{ance of open}\\\text{wire to fault}\end{matrix}\right\}=L\left\{\begin{matrix}\text{overall}\\\text{loop re-}\\\text{sistance}\end{matrix}\right\}-R_{AB}\left\{\begin{matrix}\text{loop resist-}\\\text{ance of near-}\\\text{end cable}\end{matrix}\right\}-R \quad (13)$$

Let us assume a case of trouble and proceed to calculate the location of the fault. Let us say that the loop test gave us a loop resistance of 550 ohms and that a balance was obtained in the Varley test when the rheostat R was set at 270 ohms. The other information necessary to calculate the location of the fault is given in Figure 57.

550 ohms, the loop resistance of the overall circuit, minus 150 ohms, the loop resistance of the cable in the circuit, equals 400 ohms, the loop resistance of the open wire. Since we have 1,600 pole sections and the loop resistance of the open wire

equals 400 ohms, the number of ohms per pole section equals

$$\frac{400}{1{,}600} = \frac{1}{4} \text{ or } .25 \text{ ohm.}$$

From equation (13) we get

$$2R_{L_s} = 550 - 80 - 270 = 200 \text{ ohms}$$

and since the loop resistance per pole section equals .25 ohm the number of sections of line from the testing station to the fault equals

$$\frac{200}{.25} = 800$$

and if the pole line numbers from the testing station, the fault should be found at pole number 801, or thereabouts.

We have taken a somewhat lengthy discussion to describe the method of determining the location of the fault but it was done with the idea of showing that the fundamental theory of the Wheatstone bridge underlies the Varley loop test which was used to solve the problem. As noted above the amount of work necessary to make the test and calculate the distance to the fault is not great. It can be summarized as follows:

First—Take loop test on overall circuit.

Second—Take Varley loop test—thereby obtaining a value R.

Third—Subtract loop resistance of cables from loop resistance of overall circuit and obtain loop resistance of open wire.

Fourth—Obtain the loop resistance per pole section by dividing the value obtained in three by the number of pole sections between the two stations.

Fifth—Add the loop resistance of the near-end cable to the value R obtained in the Varley loop test.

Sixth—Subtract the value obtained in five from the value obtained in overall loop test.

Seventh—Divide the value obtained in six by the value obtained in four and obtain the number of pole sections to the fault.

In order to determine the distance from the distant station to the fault let us consider formula (8)

$$R_{L_2}+R_{L_3}=R_{L_1} \quad (8)$$

$$R_{L_3}=R_{L_1}-R_{L_2} \quad (14)$$

substituting this value in equation (7) we have

$$R+R_b+R_{L_1}-R_{L_2}=R_a+R_{L_1}+R_c+R_d+R_{L_2} \quad (15)$$

$$R+R_b+R_{L_1}-R_a-R_{L_1}-R_c-R_d=2R_{L_2} \quad (16)$$

Since $R_b = R_a$ and $R_c + R_d = R_{cd}$, the loop resistance of the distant cable, we have

$$2R_{L_2}\left\{\begin{matrix}\text{loop resistance}\\ \text{from distant}\\ \text{station to fault}\end{matrix}\right\}=R-R_{cd}\left\{\begin{matrix}\text{loop resistance}\\ \text{of distant}\\ \text{cable}\end{matrix}\right\} \quad (17)$$

that is the loop resistance of the open wire from the cable terminal at the distant station to the fault equals the difference between the value R obtained in the Varley loop test and the loop resistance of the distant cable.

Using formula (17) to check the result obtained in the calculation given above we should arrive at the same pole location for the vault. By substituting the values given above in equation (17) we have

$$2R_{L_2}=270-70=200 \text{ ohms}$$

$$\frac{200}{.25}=800 \text{ pole sections}$$

or the trouble should locate at pole 801.

In the preceding paragraphs we have considered an application of the Varley loop test in determining the location of a fault on an open-wire line. There are many different kinds of troubles and circuit conditions in the plant and each case requires individual study in order that a good fault location may be obtained. We may encounter an open-wire line with one or more intermediate cables in it. It will then be necessary to consider the cables as equivalent to a definite number of sections of open wire. It is of course possible to work out formulæ which will allow us to eliminate the cable in the line when calculating for a fault and in certain cases it would be desirable to do so. By applying the reasoning used above it is possible to develop formulæ which will fit such special cases.

It will be well, however, to consider a somewhat general application of the Varley loop test. In the following formula the distance from the testing station to the fault can be determined.

$$d = \frac{L - R}{M} \qquad (18)$$

Where d = Distance from testing station to fault
R = Resistance in rheostat arm when a balance is obtained
L = Loop resistance of the line under test
M = Loop resistance per mile of line under test.

For example if the loop resistance of a line 60 miles long is 600 ohms at the time the Varley loop test is made, the loop resistance at that time is 10 ohms per mile. If a balance is obtained when making the Varley test with a resistance of 200 ohms in

the rheostat arm and with the ratio arms equal, we have by substituting in formula (18)

$$d = \frac{600 - 200}{10} = 40 \text{ miles, the distance from the testing station to the fault.}$$

The distance between the fault and the distant station is obtained by the formula

$$d_1 = \frac{R}{M} \qquad (19)$$

Where d_1 = Distance from fault to distant station
R = Resistance in rheostat arm when a balance is obtained
M = Loop resistance per mile of the line under test.

Thus in the example given above

$$d_1 = \frac{200}{10} = 20 \text{ miles, the distance from the fault to the distant station.}$$

It should be noted that in the formulæ given above the conductors of the circuit under test are assumed to have the same gauge and conductivity throughout their entire length. Proper correction will have to be made for the cable in the circuit in a similar manner to that previously explained for intermediate cables.

It is possible that the circuit under test may have more than one ground on the conductor which is in trouble. Such a condition is shown in Figure 58. In this case the location of the fault will appear to be midway between the two troubles at a point c. This can be seen by working out formulæ (14) and (17). If formulæ (18) and (19) are used it will be necessary to eliminate the resistance in the

terminal cables in order to clearly bring out this point. Conditions such as shown in Figure 58 must be anticipated for it is possible that if one trouble

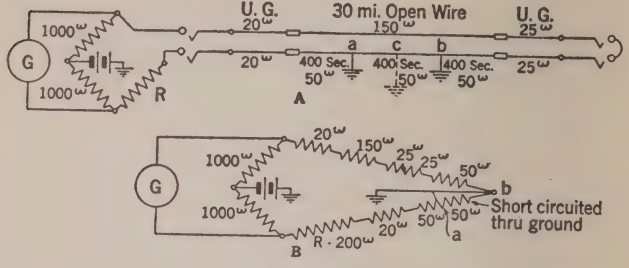


Fig. 58

exists there might be others in the circuit to upset a location test. However, by applying the fundamental principles of the Wheatstone bridge to the problem it is possible to arrive at some sort of solution. For example in the case of the condition shown in Figure 58, if the ground at a has a low resistance and earth potential does not interfere with the test it is possible to determine the distance of the a fault from the test station by means of the single wire resistance test where the earth is used as a return.

If the lineman is at point c he can place a short on the pair at this point and by making a Varley loop test the single wire resistance from point c to a can be roughly approximated. The resistance in the rheostat R gives this resistance directly when the ratio arms are equal.

Single Wire Resistance Measurements with Varley Loop

When two good wires are available the resistance of either of them may be determined more accurately by means of the Varley or Murray loop test than with the single wire resistance measurement with the distant end grounded. To do this the loop resistance is first measured and then both wires are connected to ground at the distant end.

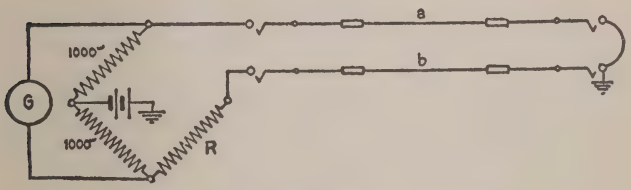


Fig. 59

See Figure 59. When a balance is obtained in making the Varley test with the ratio arms **A** and **B** equal the resistance in the rheostat arm **R** indicates the number of ohms by which the resistance of wire **a** exceeds the resistance of wire **b**. One-half the sum obtained by adding this resistance to the loop resistance will then be the resistance of wire **a**. Note the manner in which wires **a** and **b** are connected to the bridge; in case wire **b** had more resistance than **a**, wires **a** and **b** would have to be reversed at the bridge. The wire with the smaller resistance must always be connected to the rheostat **R**. It is assumed that in determining the resistance of a single wire in this manner that both wires are free from crosses and grounds.

This test is very useful in determining whether a lineman has gone by his trouble. We saw one application in Figure 58. Figure 60 shows a condition where one ground is involved. If wires **a**

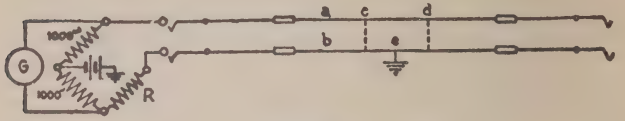


Fig. 60

and **b** each have the same resistance and the lineman should place a short at **c** the rheostat **R** would be at zero. (If, however, wire **a** did not balance with wire **b** as regards resistance, rheostat **R** would contain resistance when the wire having the lower resistance was connected to it.) If the lineman placed a short at **d** a reading would be obtained in **R** indicating that the lineman had gone by his trouble. The resistance in **R** would be the approximate single wire resistance between the lineman and the fault. Occasionally a resistance unbalance between the two wires of the circuit under test is confused with the single wire resistance from the lineman's "short" to the fault. This condition must be guarded against and can be determined by making a single wire resistance test to the pole at which the lineman is testing.

Varley Loop Test with Unequal Ratio Arms

It may be necessary in some cases to make a Varlep loop test with unequal ratio arms in order to obtain a more accurate balance than when the ratio arms are equal.

Figure 61 shows a circuit set up similar to that shown in Figure 57 except that the ratio arms **A** and **B** are not equal. Applying the same reasoning in this case as we did for Figure 57 we arrive at the following.

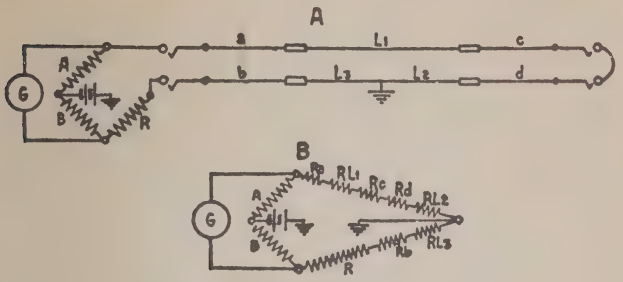


Fig. 61

$$\frac{A}{B} = \frac{R_a + R_{L_1} + R_c + R_d + R_{L_2}}{R + R_b + R_{L_3}} \qquad (20)$$

Since we are interested in the resistance R_{L_3} in order to determine the distance L_3 we will solve for it.

$$AR + AR_b + AR_{L_3} = BR_a + BR_{L_1} + BR_c + BR_d + BR_{L_2} \qquad (21)$$

$$\text{or } R_{L_3} = \frac{BR_a + BR_{L_1} + BR_{cd} + BR_{L_2} - AR - AR_b}{A} \qquad (22)$$

We therefore know the single wire resistance from the cable terminal at the testing end to the fault.

From the loop measurement we can obtain the single wire resistance per pole section or per mile and thereby obtain the pole number at which the trouble should be found.

A more general formula which can be used to obtain the location of the fault where the ratio arms **A** and **B** are unequal, is

$$d = \frac{D^1(BL - AR)}{L(A + B)} \qquad (23)$$

Where d = Distance from the testing station to the fault
D^1 = Twice the distance between the testing station and the distant station
L = Loop resistance of the pair under test
A and B = Resistance in the ratio arms **A** and **B**
R = Resistance in the rheostat arm when a balance is obtained.

The proof of this formula is similar to that for equation (18) and is as follows. See Figure 62.

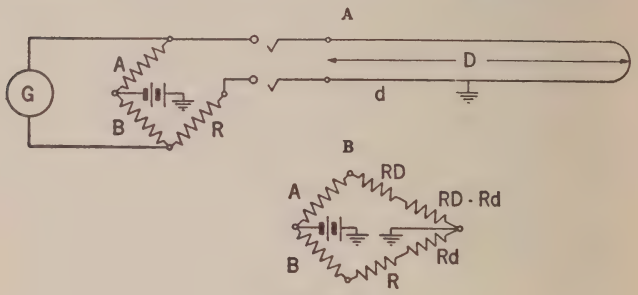


Fig. 62

$$\frac{A}{B} = \frac{R_D + R_D - R_d}{R + R_d} \qquad (24)$$

$$AR + AR_d = BR_D + BR_D - BR_d \qquad (25)$$

$$R_d(A + B) = 2BR_D - AR \qquad (26)$$

$$R_d = \frac{2BR_D - AR}{A + B} \qquad (27)$$

$$L = 2R_D \qquad (28)$$

The single wire resistance per mile equals $\frac{L}{2D}$.

$$R_d = \frac{L}{2D} \times d \qquad (29)$$

$$\text{let } 2D = D^1 \qquad (30)$$

therefore $$\frac{L}{D^1} \times d = \frac{BL - AR}{A + B} \qquad (31)$$

or $$d = \frac{D^1(BL - AR)}{L(A + B)} \qquad (32)$$

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-B

ELECTRICAL MEASUREMENTS AT TOLL TEST BOARDS

PART IV

Murray Loop Test

The Murray loop test also affords a means of locating a fault in such a way that the result is independent of the resistance of the fault itself. Here again as in the Varley loop test it is important to have the good wire of the same gauge, length and conductivity as the bad wire. The circuit arrangements when making Murray loop tests are shown in Figures 63, 64 and 65. We will note that the **B** arm is shorted out and the **R** arm substituted by shifting the galvanometer to the line side of the **R** arm. However, the fundamental Wheatstone bridge circuit is maintained. The four arms are the ratio arm **A**, the rheostat arm **R**, one side of the line from the testing station to the fault, and one side of the line from the fault to the distant station and back to the testing station.

In making the Murray loop test arm **A** is usually set at 1,000 ohms and the bridge is adjusted in the usual way. If a more accurate result is desired arm **A** should then be adjusted as nearly as possible to a value equal to one-half the loop resistance and another balance obtained. When a balance is obtained the location of the fault may be determined by means of the formula,

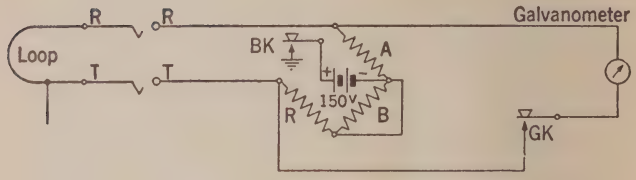
$$d = \frac{D'R}{A + R} \qquad (33)$$

where d = Distance from testing station to the fault
D' = Twice the distance between the testing stations
R = Resistance in the rheostat arm when a balance is obtained
A = The resistance in arm **A**.

Thus, if the distance between testing stations is 40 miles and if a balance is obtained in making the Murray loop test when

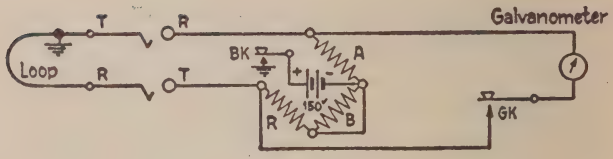
$$A = 1{,}000 \text{ ohms and } R = 600 \text{ ohms,}$$

$$d = \frac{40 \times 2 \times 600}{1{,}000 + 600} = 30 \text{ miles, the distance from the testing station to the fault.}$$



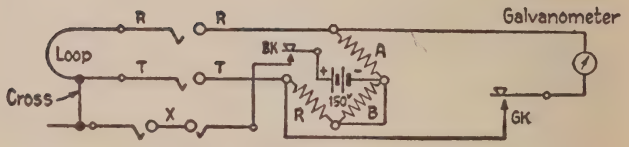
Murray loop test

Fig. 63



Reversed Murray loop test.

Fig. 64



Metallic Murray loop test

Fig. 65

This result may be checked by reversing the line at the bridge. The value of d determined by formula (33) is then the distance from the testing station to the distant station and back to the fault. Thus in the above case if the line is reversed and a balance obtained when R = 1,667 ohms, according to formula (33), $d = \frac{40 \times 2 \times 1{,}667}{1{,}000 + 1{,}667} = 50$ miles, the distance from the testing station to the distant station and back to the fault. Adding these two values of d, we have $50 + 30 = 80$ miles, which is twice the distance between testing stations.

Formula (33) applies when the two wires under test are of the same gauge and conductivity throughout their length. In such cases this formula is more convenient than formula (18) when the lineman is working from the testing station toward the fault, since it is not necessary to know the loop resistance to locate the fault.

Single Wire Resistance Measurements with Murray Loop

When two wires are available between testing stations, the resistance of either of them may be determined by measuring their loop resistance and then making a Murray loop test with both wires grounded at the distant station in a manner similar to that previously described for Varley loop tests. When a balance is obtained the resistance in the tip side of the line or the odd numbered wire of the pair will be given by the formula,

$$Y = \frac{RL}{A + R} \qquad (34)$$

Where Y = The resistance of wire on the tip side of the line from the testing station to the distant station.
L = Loop resistance of the two wires.
R = Resistance in the rheostat arm when a balance is obtained.
A = The resistance in ratio arm **A**.

For example, suppose the loop resistance of the two wires is 240 ohms and when making the Murray loop test with both wires grounded at the distant station a balance is obtained when A = 1,000 ohms, and R = 715 ohms. Then substituting in formula (34) $Y = \frac{715 \times 240}{1{,}000 + 715} = 100$ ohms, the resistance of the wire in the tip side of the line.

This value may be checked by reversing the line and again obtaining a balance. The value of "Y" obtained from formula (34) will then be the resistance in the ring side of the line and this value added to the value obtained for the resistance in the tip side should be equal to the loop resistance of the line under test. Thus in the example given above if a balance is obtained with the line reversed when A = 1,000 ohms and R = 1,400 ohms,

$$Y = \frac{1{,}400 \times 240}{1{,}000 + 1{,}400} = 140 \text{ ohms},$$

the resistance in the ring side of the line.

This value added to the value previously obtained for the tip side gives 240 ohms, the loop resistance of the line under test.

Varley and Murray Tests When a Good Wire of the Same Gauge As the Bad Wire Is Not Available.

When a good wire of the same gauge as the bad wire is not available it is necessary to know the resistance of the bad wire from the testing station to the distant station before an accurate location can be made. If the bad wire is grounded the single wire resistance measurements described above can not be employed for determining the resistance of the single wire. In such cases the bad wire and good wire should be strapped at the distant end and their loop resistance measured. If a third wire of any gauge or conductivity which is free from crosses or grounds is available the three wires should be strapped at the distant station and the third wire at the testing station connected to the bridge in a manner as shown for wire **X** in Figures 56 and 65. A Varley or Murray loop test may then be made in exactly the same way as described above for measuring single wire resistances and the same formulæ apply in calculating the resistance of the bad wire.

Having determined the resistance of the bad wire between the two testing stations, the Varley or Murray loop tests should then be made for locating the fault. It will sometimes be found when the bad wire is of a smaller gauge than the good wire that a balance can not be obtained when the bad wire is connected to the tip side of the bridge. In such cases the reversing key at the test panel should be operated which reverses the connection of the tip and ring wires at the bridge.

In making the Varley loop test with the ratio arms **A** and **B** equal the resistance in the bad wire between the testing station and the fault is given by the formula,

$$X = \frac{L - R}{2} \qquad (35)$$

Where X = The resistance of the bad wire from the testing station to the fault.
L = Loop resistance of the pair consisting of the good and bad wire of different gauges.
R = The resistance in the rheostat arm **R** when a balance is obtained.

For example, assume that the loop resistance of the pair under test is 400 ohms. If a Varley loop test be made on the pair with the ratio arms **A** and **B** equal and a balance is obtained when the rheostat arm **R** is set at 150 ohms, the resistance of the bad wire from the testing station to the fault is,

$$X = \frac{400 - 150}{2} = 125 \text{ ohms.}$$

If the resistance in the bad wire from the testing station to the fault is greater than the resistance in the good wire from the testing station to the distant station, and back to the fault, as might be the case if the fault were near the distant station, it will be necessary to reverse the line at the bridge to obtain a balance if equal ratio arms are used. When this is done the resistance to the fault is expressed by the formula,

$$X = \frac{L + R}{2} \qquad (36)$$

Where X, L and R have the same values as above.

Thus in the above case, suppose a balance is obtained with the line reversed (which is accomplished by operating the reversing key) and R = 30 ohms. Then, we have by substituting in formula (36) $X = \frac{400 + 30}{2} = 215$ ohms, the resistance in the bad wire from the testing station to the fault.

It is to be noted that formulæ (35) and (36) apply when the trouble is on the tip side of the line. If the trouble is on the ring side of the line the application of these formulæ should be reversed.

Having determined the resistance to the fault and the resistance of the bad wire between the two testing stations, the distance to the fault can be calculated by means of the formula,

$$d = \frac{XD}{r} \qquad (37)$$

Where d = Distance from the testing station to the fault.
X = Resistance of the bad wire from the testing station to the fault.
r = The resistance of the bad wire from the testing station to the distant station.
D = Distance between the two testing stations.

Thus, suppose the distance between the two testing stations is 50 miles, and the resistance of the bad wire from the testing station to the distant station, as determined by the single wire resistance measurement, is 225 ohms. Then, if the resistance

in the bad wire from the testing station to the fault is 125 ohms, the distance to the fault is

$$d = \frac{125 \times 50}{225} = 27.7 \text{ miles},$$

the distance from the testing station to the fault.

If the Murray loop test is used in making the location test and a balance is obtained when the trouble is on the tip side of the line, the resistance to the fault is given by the formula,

$$X = \frac{RL}{A + R} \qquad (38)$$

Where X = Resistance of the bad wire from the testing station to the fault.
L = Loop resistance of the pair consisting of the good and bad wires of different gauges.
R = The resistance in rheostat arm **R** when a balance is obtained.
A = Resistance in ratio arm **A**.

For example, suppose the loop resistance of the pair under test is 400 ohms and a balance is obtained when making the Murray loop test when **A** = 100 ohms and **R** = 60 ohms. Substituting in formula (38) we have $X = \frac{60 \times 400}{100 + 60} = 150$ ohms, the resistance in the bad wire from the testing station to the fault.

If the reversing key is operated while obtaining

a balance the resistance to the fault is obtained by the formula,

$$X = \frac{AL}{A + R} \qquad (39)$$

Where **A**, **L** and **R** have the same values as above.

Thus, in the above case, suppose the reversing key is operated and a balance is obtained when **A** = 100 ohms and **R** = 167 ohms. Substituting in formula (39) we have $X = \frac{100 \times 400}{100 + 167} = 150$ ohms, the resistance in the bad wire from the testing station to the fault.

As in the case of the Varley loop test, formulæ (38) and (39) apply when the trouble is on the tip side of the line and their application should be reversed when the trouble is on the ring side.

When the resistance from the testing station to the fault has been determined, the distance to the fault may be determined by means of formula (37) which applies to both Varley and Murray loop tests.

Swinging Faults

In making Varley or Murray loop tests on a line where the ground or cross is intermittent it may be desirable to insert a Morse relay in the grounded side of the testing battery. This can be done on the No. 4 board. This arrangement causes the Morse relay to operate each time the battery key on the bridge is closed if the circuit is grounded

or crossed, thereby indicating to the test board operator that the trouble is present and that he may proceed to balance the bridge.

Location of Crosses

As there is usually an appreciable resistance in a "cross," which may vary in amount during the test due to corrosion of the wires or poor contact between them the measurement of the loop resistance through the cross itself does not afford a reliable means for locating the fault. For this reason a Varley or Murray loop test should always be used when attempting to locate a cross. Unless there is a considerable leakage in the line, the accuracy of the Varley or Murray loop tests will not be affected by the resistance in the cross itself.

In locating a cross by either the Varley or Murray loop tests one of the faulty wires should be strapped at the distant station to a good wire, preferably its mate, and the loop resistance of the two measured. The other faulty wire which is crossed with the faulty wire of the loop being measured is then connected to ground at the testing station. If, for example, wires 2 and 3 are crossed and wire 1 is free from faults and the same gauge as wire 2, wires 1 and 2 should be strapped at the distant station and wire 3 connected to ground at the testing station. The Varley and Murray loop tests may then be made in the usual way and the distance to the fault calculated by means of Formula (18) or (33).

If the crossed wires are of the same gauge and conductivity and the resistance of the cross re-

mains constant a check test may be made by opening both wires at the distant station and measuring the loop resistance through the cross and then making a Varley loop test with one of the wires grounded at the distant end. The resistance determined by the Varley measurement will then be the resistance of the cross itself and this resistance subtracted from the loop resistance through the cross will be the loop resistance of the two wires to the fault.

Location of Crosses with Metallic Battery

During bad weather the accuracy of the Varley or Murray loop tests made with grounded battery will be affected by the line leakage to ground. A more accurate location of a cross may be made under these conditions by employing metallic instead of grounded battery. This may be accomplished by employing the method described above except that wire 3 should be connected to the bridge as shown in Figures 56 and 65, instead of being connected to ground. The Varley or Murray loop tests may then be made in the usual way.

SPECIFIC APPLICATIONS—MEASURING WORK AT TEST BOARDS

SECTION IV-B

ELECTRICAL MEASUREMENTS AT TOLL TEST BOARDS

PART V

Open Location Test

This test is essentially a capacity measurement, the Wheatstone bridge being used with low frequency alternating current as a means for comparing the capacity between the open wire and ground with that of an accurate 1-microfarad condenser at the test board. In making open-location tests the Murray loop connection is employed, the ratio arm **A** and the rheostat arm **R** forming two arms of

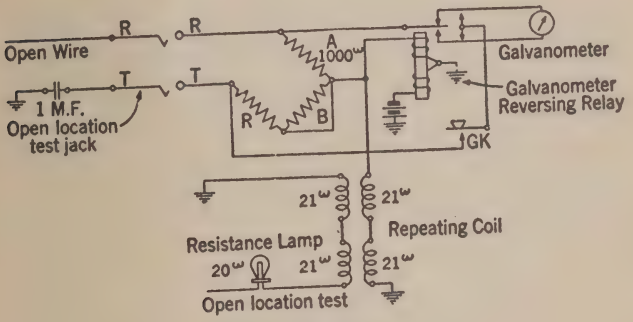


Fig. 66

the bridge and the open wire and the grounded condenser forming the other two arms. See Figure 66. When the rheostat arm **R** is adjusted until no current flows through the galvanometer, the resistances in the arms **A** and **R** are inversely proportional to the capacities of the line and condenser, or

$$\frac{A}{R} = \frac{C_1}{C_2}$$

where C_1 equals the capacity of the grounded condenser in the testing circuit, C_2 is the distributed

capacity between the open wire and ground, and A and R the resistances in the bridge arms **A** and **R**.

In making open-location tests arms **A** should always be set at 1,000 ohms, then since C_1 is one microfarad, the above formula may be simplified to the form

$$C_2 = \frac{R}{1{,}000} \qquad (40)$$

which is the distributed capacity between the open wire and ground when a balance is obtained. Thus, suppose in making an open-location test or capacity measurement a balance is obtained when $R = 90$ ohms. Then the capacity between the open wire and ground or the capacity of the apparatus being measured is

$$C_2 = \frac{90}{1{,}000} = .09 \text{ microfarad.}$$

Since the distributed capacity of a line to ground for a short line is nearly proportional to its length, this measurement affords a simple means for determining the distance to the point where the line is open. This relation holds sufficiently well for all practical purposes in locating opens on loaded or non-loaded open-wire lines up to 200 miles in length or on loaded or non-loaded cable up to 40 miles in length. The measurements are less useful when the open is further away from the testing station since the resistance and inductance in the line cause the relation between the capacity and length to vary.

The open-location test also affords a convenient means of measuring the capacity of the condensers in circuits other than line circuits, the testing circuit being connected to the circuit or apparatus to be measured in the same way as to an open wire. When a balance is obtained formula (40) may be used for calculating the capacity.

The open-location test may also be used to advantage to determine which wire of a pair is crossed with another circuit when this fact can not be determined conclusively by voltmeter or listening tests, since the capacity of the wire which is crossed will generally be considerably larger than the capacity of the good wire.

After determining which wire of the pair is open, the line under test is connected to the bridge circuit as shown in Figure 66 by selecting the proper apparatus on the No. 4 board. Plugging into the open-location test jack operates a relay in the Wheatstone bridge circuit which connects alternating current through the repeating coil to the junction of the bridge arms and starts the operation of the galvanometer-reversing relay. By making and breaking only once per cycle the galvanometer-reversing relay serves to reverse the connection to the voltmeter or galvanometer in such a way that the current will pass through it in one direction only. Ratio arm **A** should then be set at 1,000 ohms, and the proper keys operated to give the Murray connection of the bridge as shown in Figure 66. The rheostat arm **R** is then adjusted until no deflection of the voltmeter is obtained when the galvanometer key is closed. The galvanometer shunt should then be placed at .1 and the proper

key thrown to connect the galvanometer in place of the voltmeter for making the final balance. It is important that the galvanometer be used in place of the voltmeter in making the final adjustment since the results obtained with the galvanometer are somewhat different from those obtained with the voltmeter. When a balance is obtained with the shunt at .1, a more accurate balance may sometimes be obtained on short lines with the shunt open. The capacity of the open wire to ground may then be obtained from formula (40) and from this value the distance to the open can be determined.

In locating an open the best results can be obtained when open-location measurements have been made previously on the line in question to points on both sides of the fault. This can be accomplished by making and recording such measurements on all lines entering the office at times when no trouble exists. The measurements on each line should include all points where appreciable electrical irregularity occurs due to any cause, such as a change in gauge or the character of the line or the occurrence of intermediate apparatus and should extend throughout the limits of the testing station concerned. The number of ohms per mile to use in the open-location test can then be determined for the various sections of all lines entering the office, and the distance between the fault and the points nearest it, where previous readings have been obtained, may be readily calculated. At the time when the open occurs a measurement should be made on the other wire of the pair, if not in trouble, or on some other wire of the same gauge and character and in the same lead, in order to determine the

number of ohms per mile to use in calculating the distance to the fault. For example, suppose no previous data are available but the mate of the open wire is free from crosses or grounds, and that the distance to the distant station is 40 miles, and, in making an open-location test on the good wire with the pair open at the distant station, a balance is obtained when R = 600 ohms. This value divided by 40 equals 15 ohms, the proper value in ohms per mile to use in calculating the distance to the fault, assuming that the wire is the same gauge and character throughout its length. Then, if on making an open-location test on the bad wire a balance is obtained when R = 345 ohms,

$\frac{345}{15} = 23$ miles, the distance between the testing station and the fault.

Where a line is made up of sections of different character, such as open wire and cable, previous data permit accurate locations to be made, and also increase the length of uniform line over which accurate locations can be made. For example, a line 55 miles long consists of 5 miles of cable and a previous reading of 450 ohms has been obtained to the end of the cable and a total reading of 1,200 ohms to the end of the line. The ohms per mile for the cable is then $\frac{450}{5}$ or 90 ohms, and $\frac{1{,}200 - 450}{50}$ or 15 ohms per mile for the open wire. If when making an open-location test on this line a balance is obtained when R = 600 ohms, the fault is 600 — 450 ohms from the end of the cable.

Since the previous reading has given 15 ohms per mile for the open wire, the distance from the end of the cable to the open is $\frac{150}{15}$ or 10 miles, so that the fault is located 15 miles from the testing station.

When neither previous data nor a good wire are available for comparison, an approximate location of the fault can be obtained by assuming a value in the open-location test of 15 ohms per mile for open-wire lines and 90 ohms per mile for cable.

It is desirable for the satisfactory operation of the open-location test that the specified electrical and mechanical adjustments of the galvanometer-reversing relay be maintained as nearly as practicable, since these adjustments affect the results obtained more than any other factor in the testing circuit. The voltage of the battery used to polarize the galvanometer-reversing relay, the speed and voltage of the generator and the load on the generator also affects the results, but the combined effect of these factors will not ordinarily amount to more than 1 per cent. when the standard adjustments of the galvanometer-reversing relay are maintained. The repeating coil which supplies alternating current to the relay and the resistance lamps in the ringing leads are important factors in the accuracy of the operation and should be maintained at all times as indicated on the drawings. The accuracy of the condenser is of considerable importance since its capacity directly affects the results to the same extent as the bridge arm. The condenser being in parallel with the galvanometer-reversing relay also affects its operation, and, for

these reasons, it is desirable to use only the condenser specified.

Fault Locations on Loaded Circuits

In order to determine the location of a fault on a loaded circuit it is necessary to take into consideration the resistance of the loading coils. As discussed in one of the preceding paragraphs on fault locations where an open-wire line has intermediate cable in the circuit it is necessary to consider this cable as equivalent to a definite length of open wire. In a like manner the resistance of the loading coils must be considered in terms of an equivalent length of the circuit in which they are connected.

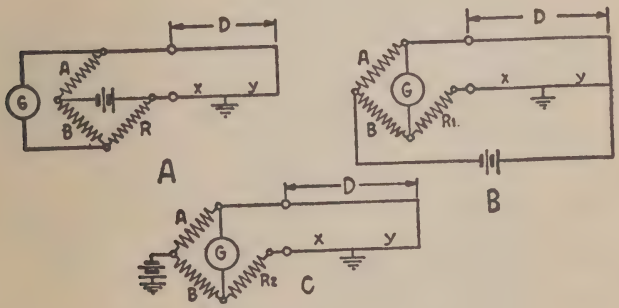


Fig. 67

Figure 67 shows sketches of the three tests necessary to secure the proper information for calculating the location of the fault. These tests have been discussed in the preceding paragraphs.

Figure 67–A shows the loop test on the circuit.

From this test we obtain the following formula

$$R_L = R\frac{A}{B} \qquad (41)$$

Figures 67–B and C show Varley loop tests from which we obtain formulæ which when properly combined with equation (41) and with each other give the following

$$X = \frac{A}{A+B}(R - R_2) \qquad (42)$$

$$Y = \frac{A}{A+B}(R_2 - R_1) \qquad (43)$$

$$X + Y = L = \frac{A}{A+B}(R - R_1) \qquad (44)$$

Let us now assume a circuit as shown in Figure 68 which is grounded on one side and determine the location of this fault. The figure gives information about the makeup of the circuit. Summarizing this we have

Total length L = 36,610 ft. of #19 gauge conductor.
Load coils are #561 for the phantom and #562 for the side circuits.
Resistance of one line winding of 561 coil = 1.5 ohms
Resistance of one line winding of 562 coil = 3.8 ohms

Total resistance of the line winding of the two coils = 5.3 ohms
124 ft. of 19 ga. cable has a resistance of 1 ohm at 68° F.
Therefore $5.3 \times 124 = 657$ ft. the equivalent length of 19 ga. cable in the loading coils at any one load point.

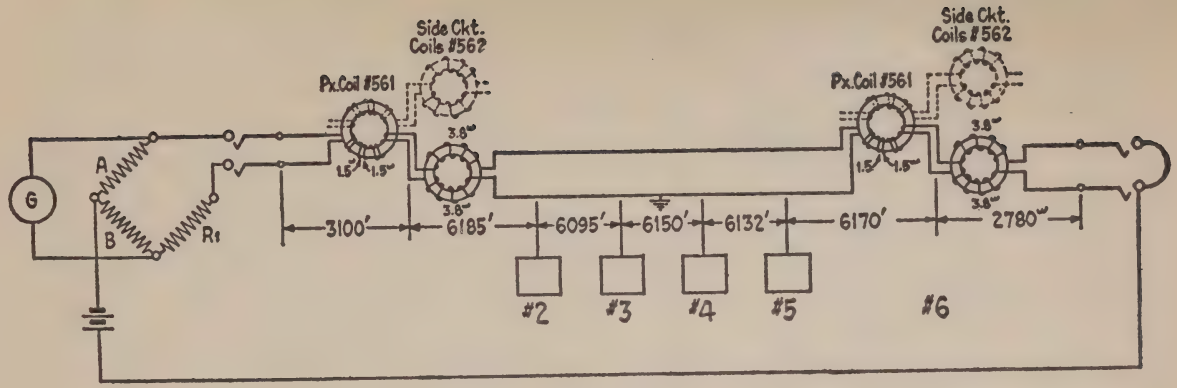

Side Ckt.
Coils #562
Px.Coil #561
Side Ckt.
Coils #562
Px.Coil #561
3.8"
1.5"
1.5"
3.8"
3.8"
1.5"
1.5"
3.8"
G
A
B
R1
3100'
6185'
6095'
6150'
6132'
6170'
2780'
#2
#3
#4
#5
#6

Fig. 68

There are six loads in the cable, therefore the total resistance of the line windings in the loading coils, between offices **A** and **B** is equivalent to $6 \times 657 = 3{,}942$ feet of 19 ga. cable.

The total equivalent length of cable between offices **A** and **B** equals $36{,}610 + 3{,}942 = 40{,}552$ feet.

Let us assume that the loop resistance $= 677.2$ ohms and that $R = 6{,}772$ ohms

$R_2 = 4{,}940$ "
$R_1 = 3{,}048$ "
$A = 100$ "
$B = 1{,}000$ "

By substituting these values in the formulæ given above we have

$$X + Y = L = \frac{A}{A + B}(R - R_1) = \frac{100}{1{,}100}(6{,}772 - 3{,}048) = 338.5 \text{ ohms.}$$

Therefore the feet per ohm $= \frac{40{,}552}{338.5} = 119.8.$

$$X \text{ ohms} = \frac{A}{A + B}(R - R_2) = \frac{100}{1{,}100}(6{,}772 - 4{,}940) = 166.5$$

$$X \text{ feet} = 166.5 \times 119.8 = 19{,}946 \text{ feet.}$$

In order to locate the trouble we will have to combine the actual length of cable in the various

load sections with the equivalent length of cable in the load coils as follows:

3,100
657
6,185
657
6,095
657

17,351 feet = equivalent distance of the 3d load from office **A**.

The trouble therefore locates 19,946 — 17,351 = 2,595 ft. from load No. 3 in the direction of load No. 4.

Direct Current Tests for Balance

In the preceding paragraphs we have considered direct current tests largely in connection with fault locations. These tests are also very useful in partially determining the electrical balance of circuits.

In Part I of this section the tests for leakage were discussed and in the preceding paragraphs of this part the series resistance tests for single wires together with the Varley and Murray unbalance tests were described. These tests should be made on sections of line which do not exceed 100 miles in length and should be made under dry weather conditions. It may be necessary in some cases to sectionalize the line when it is too long and test from each terminal to the intermediate point.

In order to prevent breaking down a high resistance joint care must be taken not to ring over a circuit which is being tested nor to connect high voltage battery to it either before or during the

test. The test voltage on the bridge should be just sufficient to produce a satisfactory deflection of the galvanometer needle and should not exceed 6 volts.

Precautions to Be Taken in the Use of Measuring Instruments

The intelligent use of electrical measuring instruments depends upon skill and care as well as an understanding of their application to each test made. A few of the more important precautions to be taken when using testing instruments are given here.

(a) **Precautions should be taken against dropping or jarring** electrical measuring instruments. Many instruments have revolving coils which are suspended in a delicate manner or mounted in jewelled bearings. Jarring may permanently damage the instruments or impair their accuracy.

(b) Electrical measuring instruments should be **kept free from dampness.**

(c) Instruments should **never** be **connected to circuits where the values** to be **measured are likely to be greater than the highest scale reading,** and the low resistance coils of a Wheatstone bridge should not have E.M.F.'s impressed across them sufficiently high to give currents greater than the carrying capacity of these coils. In general, for ordinary testing, the **A** and **B** arms should not be set upon low values if the voltage of the testing battery is comparatively high.

(d) **Milli-ammeters and milli-voltmeters are designed for measuring milli-volts and milli-amperes, not volts and amperes.**

(e) **Ammeters must always be inserted in series** and never across any branch or any part of an electrical circuit.

(f) In any Wheatstone bridge test, the **galvanometer and the battery key should NOT BE CLOSED excepting when the** tester is actually endeavoring to obtain a bridge balance. If the galvanometer is equipped with a shunt, **the lowest resistance shunt should be bridged across the galvanometer when beginning** to obtain a balance. When an approximate balance is obtained in this way, the next lowest value shunt should be bridged, and thus by degrees the galvanometer coil may be connected into the circuit.

(g) In making Wheatstone bridge measurements, **precautions should be taken against sources of E.M.F. such as ringing current, cords with battery, Morse legs, etc.,** being connected to the circuit at the distant end or at some intermediate point while the Wheatstone bridge test is being made.

(h) For accuracy when reading scales of electrical instruments, **the eye should be directly over the needle,** that is, the line of vision should be perpendicular to the scale. Some instruments are equipped with small mirrors beneath the needle in order to avoid reading the scale at an angle. When the image of the needle in the mirror is directly beneath the needle, the eye is perpendicular to the scale.

(i) Some instruments are designed for reading when mounted vertically; others for reading when mounted horizontally. In general, all portable instruments are designed for reading horizontally. Mountable instruments such as meters for power boards, etc., are designed for reading when vertical.

(j) When an indicating instrument is not connected, the needle should stand on zero of the scale. Most instruments are equipped with some device such as a screw head adjustment for correcting the zero position of the needle.

(k) Delicate instruments are usually equipped with some device for clamping the needle when not in use. This often prevents damage from jarring. Instruments not equipped with a clamping device may have their coils "dampened" by short-circuiting their terminals. Care must be taken that the short circuit is removed before using the instrument.

(l) Errors are often encountered in Wheatstone bridge measurements on long open wire and cable circuits due to foreign potentials caused by induction, ground potentials, etc. To correct for these, it is often necessary to reverse the polarity of the testing battery and make a second measurement. The average of the two measurements may be recorded as the one to use.

(m) In making Wheatstone bridge measurements, precautions should be taken that the circuit under test is absolutely cleared of all bridged or other apparatus not permanently associated with the circuit and essential for giving simple continuity.

(n) **Beware of loose connections.** Make sure that all connections to binding posts or elsewhere have zero resistance. Do not use high resistance wires for leads.

(o) **Make a mental estimate of the value you expect to read** from your knowledge of the conditions, or, in other words, guess at the value before measuring. This will often prevent mistakes due to errors that are obvious and will usually prevent the improper use of the instruments.

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